EFFECTS OF METABOLIC MODIFIERS AND ENVIRONMENT ON CATTLE HEALTH AND PERFORMANCE

by

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Abstract:

Holstein steers (*n* = 855; initial BW = 448 $\pm$ 37 kg) were used in an experiment to determine the effects of dose (0, 300, or 400 $mg \cdot hd^{-1} \cdot d^{-1}$) and duration (28, 35 or 42 d) of ractopamine hydrochloride (**RH**) on growth, performance, and carcass characteristics. Duration did not affect performance or carcass characteristics ($P \geq 0.12$). Increasing RH dose tended to increased final BW ($P = 0.07$), increased ADG ($P = 0.002$), G:F ($P = 0.002$) but did not affect DMI ($P = 0.84$). Hot carcass weight and LM area increased with increasing RH dose ($P \leq 0.001$) and calculated yield grade and marbling score decreased with increasing RH dose ($P \leq 0.03$). Black-hided feedlot steers (*n* = 143; initial BW = 392 $\pm$ 22 kg) and red-hided replacement heifers (*n* = 25; initial BW = 450 $\pm$ 46 kg) were used in an experiment to determine the effect of environment on rumen temperature (**RuTemp**). Comprehensive climate index (**CCI**) and stress thresholds were used to assess the effects of multiple environmental variables into one index. Rumen temperatures were highest in PM and lowest in AM periods for steers ($P < 0.001$) and heifers ($P < 0.001$). For steers and heifers, RuTemp were impacted by CCI and environmental conditions. Feedlot steers in Exp. 1 (n = 54; BW = 391 $\pm$ 13 kg) and Exp. 2 (n = 72; BW = 380 $\pm$18 kg) were used to predict daily water intake (**DWI**) based on changes in RuTemp. The following equation was used to predicted DWI: -59.04 + 1.41(water temperature) + 1.59(DMI) + 0.76(Average CCI) + 0.50(maximum CCI) + 0.23 (RuTemp deviation). As CCI stress threshold increased, DWI increased ($P < 0.001$) and DMI ($P = 0.02$) decreased. Continuous RuTemp monitoring can be utilized to predict DWI of feedlot steers.

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Document Nomenclature

ADF – Acid detergent fiber

ADG – Average daily gain

AM – Morning; 0600 to 1159

ASTM – American Society for Testing and Materials

AT – Ambient temperature

AUC – Area under the curve

βAA – Beta-adrenergic agonist

BT – Body temperature

cAMP – Cyclic adenosine monophosphate

CBT – Core body temperature

CCI – Comprehensive climate index

CCI:RuTemp – Comprehensive climate index to rumen temperature ratio

CON – control; no ractopamine feed

CON2 – Conventional

CONV – Conventional production system

DART – Depression, abnormal appetite, respiratory and temperature

DDGS – Dried distiller's grains plus solubles

DM – Dry matter

DMI – Dry matter intake

DWI – Daily water intake

E-AM – Early Morning; 0000 to 0559

E-PM – Early afternoon; 1200 to 1759 h

FDA – Food and Drug Administration

FWI – Free water intake

GPT – Growth promoting technologies

HCW – Hot carcass weight

HS – Heat stress

HSP – Heat stress protein

IDE – Individual drinking events

InSt – Insentec feeding system

LM – Longissimus muscle

LOESS – Local regression

NAT – Natural production system

NBQA – National Beef Quality Audit

NCON – Non-conventional

NEB – Negative energy balance

NEFA – Non-esterified fatty acid

PM – Evening; 1800 to 2359 h

PS – Panting score

ReTemp - Rectal temperature

RH – Ractopamine Hydrochloride

RHum – Relative humidity

RR – Respiration rate

RuTemp – Rumen temperature

RuTemp:CCI – Rumen temperature to CCI ratio

SR – Solar radiation

SSF – Slice shear force

THI – Temperature-humidity index

TNZ – Thermoneutral zone

TOD – Time of day

TWI – Total water intake

WaTemp – Water temperature boluses

WBSF – Warner-Bratzler shear force

WS – Wind speed

WSBRC – Willard Sparks Beef Research Center

ZH – Zilpaterol hydrochloride

CHAPTER I

INTRODUCTION

The use of technologies within the beef industry is beneficial to increase efficiencies and profitability, increase the production of high-quality beef, and decrease inputs needed. The cattle industry is faced with many challenges that may decrease efficiency of the animals. These challenges include consumer perspective, severe environmental conditions, and decreased land and feed resources. Ruminant animals continue to play a unique and essential role in meeting the demand for food because of their unique relationship with extensive landscapes, inedible by humans, to create high-quality animal proteins (Caton and Olson, 2016). The use of Holstein steers within the feedlot industry is beneficial because of their increased carcass weight, predictable gains, and decreased disease rates (Duff and McMurphy, 2007). The addition of ractopamine hydrochloride (**RH**) in the last 28 to 42 d increases ADG, efficiency, and carcass weight, especially in Holstein steers (Vogel et al., 2009). Research on the use of RH in Holstein steers is limited when determining the effect of length of feeding at various dosages.

Previous research has shown that extended exposure to high-heat environmental conditions has a negative impact on cattle welfare, performance, and milk production (Ammer et al., 2014; Gaughan and Mader, 2014; Gaughan et al. 2008). Body temperature in cattle fluctuate throughout the day and is dependent on environmental exposure, rate of fermentation, and stage of production. Heat stressed cattle are dependent on the exchange of heat into the environment, although when environmental temperatures are greater than body temperature heat exchange does not occur (Davis et al., 2013). Limited research is available in determining body temperature fluctuations are different environmental stress thresholds. In 2010, Mader et al. created the comprehensive climate index (**CCI**) that has potential in assessing environmental effects on animal health, comfort, maintenance, and productivity. The CCI is broken down into stress thresholds ranging from no stress to extreme danger. Limited research is available in defining the body temperature response at each of the CCI thresholds.

Water intake in cattle is highly variable and is dependent on several factors. These include body composition, environmental conditions, feed intakes, water composition, and water temperature. Water can be provided in one of three ways; 1) water consumption, 2) moisture provided within feed, and 3) metabolic water production (Utley et al., 1970). Predicting water intake in cattle has been proven a challenge due to the extensive relationship between vast numbers of factors. Previous research has estimated water intake in beef cattle with visual observation (Arias and Mader, 2011). Accurate prediction of water intake for beef cattle is beneficial because it can ensure that adequate water is provided to cattle during various environmental conditions. Continuous monitoring of body temperature through rumen temperature boluses have been proven to be beneficial in predicting illnesses, estrous, gestation, and heat stress in dairy cows and beef cattle (Boehmer et al., 2015; Cooper-Prado et al., 2011; Haviland, 2013; Rose-Dye et al., 2011;

Wright et al., 2014). Limited research is available to define the effects of water intakes on rumen temperature of beef cattle.

Increasing the efficiency of beef cattle can be achieved through several ways including the use of growth technologies, improving mitigation management techniques to decrease heat stress, and providing adequate water. The objectives of the experiments within this document include: 1) effect of feeding RH at varying doses and duration on the growth, performance, and carcass characteristics in feedlot Holstein steers; 2) determine the impact environmental conditions have on rumen temperature of beef cattle; and 3) predict water intakes with rumen temperature in beef cattle.

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CHAPTER II

REVIEW OF LITERATURE

The cattle industry is faced with several challenges to increase profits, productivity, and quality of outputs while maintaining efficiency and sustainability. Ruminant animals are unique in their ability to sustainably convert forages from grazing lands and byproducts from human food, fiber, and fuel production into high quality, nutrient dense human foods (Caton and Olson, 2016). In the future, the U.S. cattle industry is faced with the challenge of producing high-quality beef for the growing demand and population while using less resources. Improving the productivity within the industry has been an ongoing process since the 1970's when the use of technologies were introduced. Since then, the beef industry has the ability to produce a higher quality and quantity of beef, with less inputs while maintaining sustainability of the system (Capper and Hayes, 2012). Outside of the industry, the use of growth technologies use not widely understood because of the increased concern about environmental impact of all food products (Capper and Hayes, 2012). To continue to increase the success of the beef industry, it is essential to continue to increase our knowledge about improving productivity and efficiency to produce high-quality animal proteins. Ruminant animals will continue to play a unique and essential role in meeting the demand for food because they have a unique symbiotic relationship with extensive landscapes that are inedible by humans to create high-quality animal protein (Caton and Olson, 2016).

Findings in reports such as the National Beef Quality Audit is used to assess the status of the industry through reports and producer related cattle and carcass traits within the beef industry (McKeith et al., 2012). Understanding the status of the industry helps to increase improvements within the cow, stocker, and feedlot sectors. Understanding challenges that are unique to each sector or common challenges across all sectors, helps to minimize losses, decrease inputs, and increase outputs and profitability for the producers. The objective of this review is to discuss the issues and challenges the beef industry faces. These challenges include, cattle type and the impact growth promoting technologies have on productivity, thermal neutral zone of cattle and how increasing environmental conditions on cattle within feedlot and pasture impact productivity, and factors that may affect water intake.

CATTLE TYPES - NATIONAL BEEF QUALITY AUDIT

The 1991 National Beef Quality Audit (**NBQA**) established the first major report on the progress of the beef industry and identified what the beef industry was producing (McKenna et al, 2002). The NBQA report is used to identify certain producer-related cattle and carcass traits in the U.S. beef industry (Boykin et al, 2017; Garcia et al, 2008; McKenna et al, 2002; Moore et al, 2012). Information in the report is used to advance improvements in genetics, management, technology use, production practices, animal handling, condemnation, carcass quality and carcass quantity factors to improve the industry and beef production (McKenna et al., 2002). Following the NBQA-1991, the in-depth summary has been repeated every 5 years to identify changes and areas that may still require focus

(Boykin et al, 2017). The purpose of repeating the report every 5 years is to measure progress regarding the quality, consistency, and competitiveness of the beef industry to be used for research settings, educational, or businesses. The NQBA asses the status of the quality and consistency of the U. S. beef industry including quantity of fed steers, heifers, and dairy breeds (McKenna et al, 2002).

Upon arrival to the packing facilities, hide color, approximate breed, and gender were assessed for all cattle. Hide color was classified according to primary color (white, black, red, Holstein, etc.) and percentage of color saturation. Dairy breed such as, Holsteins or Jersey breeds, were classified into their own category for all parameters. Prior to 2000, hide color, gender, and breed were not assessed in the NBQA, but all were added to future surveys. In addition to hide color, with breed, gender, and country of origin were added to the assessment in 2010 (McKenna et al., 2002; Moore et al., 2012; Boykin et al., 2017). Over the history of the NBQA report, the percentage of Holstein steers in the fed cattle market has increased at a steady rate, 5.7% in 2000, 7.9% in 2005, 9.9% in 2011, and 15.9% in 2016. Whereas the percentage of beef breeds within the fed cattle market has stayed consistent from 2005 to 2016 assessments; 85.8% in 2005, 88.3% in 2011, and 82.9% in 2016 (Boykin et al., 2017; Garcia et al., 2008; McKenna et al., 2002; Moore et al., 2012).

The increase in the use of Holstein steers in feedlots can be contributed to the success of the dairy industry, the lack of need for bulls, and the increased demand for animal proteins. The dairy industry has a 30 to 35% turnover rate of cows. This retention rate increases the importance of heifer replacement to continue the success of the dairy industry (Peters, 2014). When colostrum and calf hutches are limited, heifer calves are given priority and bull calves are pushed through the system and shipped to growing yards to prepare them for entry into the feedlot. Typically Holstein bulls are not utilized within the dairy sector because of their increased size, aggressive temperament, and the increase in the use of artificial insemination practices. Generally, Holstein calves are separated from their mothers immediately after birth, fed colostrum, and raised in either individual or group hutches. After transportation, bulls are castrated and sent to calf ranches at a few days old where they are grown in a backgrounding environment where they are transitioned onto a high-concentrate starter diet.

Calf ranches have proven to be beneficial for Holstein steers and their transition into the feedlots when compared to conventional beef breed calves (Amachawadi and Nagaraja, 2016). These advantages include introduction of calves to concentrate diets to develop the microbial populations within the rumen, use of feed bunks and waterers, human interactions, and decreased comingling among calves from several ranches. Previous research has shown that Holstein steers in calf ranches prior to introduction into the feedlot have less incidence of disease, higher compensatory gains, and overall better health (Amachawadi and Nagaraja, 2016). Bernal-Rigoli et al (2012) found when group housing was used to raise Holstein calves prior to the feedlot, rumen microbes matured sooner, less illness, and greater feed intakes, when compared to beef calves that were weaned just before entry into the feedlot. While fed in calf ranches, group feeding, beneficial for increasing feed intakes, decreased presence of disease, and increased daily gain when compared to calves that were fed in individual huts (Bernal-Rigoli et al., 2012). Luckily, for the feedlot, professional calf ranches receive day-old calves and rear them into healthy, uniform, feedlot ready calves (Peters, 2014).

In 2007, it was estimated that approximately 90% of dairy cattle in the United States were of the Holstein breed. The dairy industry produces approximately 3 million Holstein calves available for replacement heifers, veal, and/or feedlots (Duff and McMurphy, 2007). As stated previously, Holstein steers made up 5.7% of the fed market in 2000 to 15.9% of the market in 2016 (Boykin et al., 2017; Garcia et al., 2008; McKenna et al., 2002; Moore et al., 2012). In the past years, an increase in Holstein calf management strategies have become available for successfully feeding Holstein steers with a profit. The primary advantage of Holstein steers is their uniform, predictive performance that may stem from uniformity due to increased genetic selection within the breed (Gant and Mader, 2010). These advantages include increased carcass weight, predictable gains and efficiencies, and decreased respiratory disease and disadvantages include increased frame size, maintenance requirements, and days on feed (Duff and McMurphy, 2007). When feeding Holstein steers in a feedlot several factors need to be taken into consideration, such as, composition of growth, feed types, economic impact, and a better understanding on the general immune status that may affect lifetime growth (Zinn et al., 2016).

Although it seems that feeding Holstein steers may potentially increase beef production in the U.S to meet the growing beef demand, there are disadvantages. Due to a larger organ size, Holstein steers have increased metabolic rates and increased maintenance requirement compared to beef breeds. Due to their increase in maintenance requirement, Holstein steers may need to be fed 250 to 400 days compared to 120 to 150 d in beef breeds and require approximately 12% more feed daily (Amachawadi and Nagaraja, 2016; Peters, 2014). Overtime, feed costs and daily yardage may put feeding Holsteins at a disadvantage if not properly managed. When managing Holstein steers it is important to monitor their progress daily to prevent digestive upsets, injury, or disease that may decrease their productivity. Due to thinner hair coat and hide, Holstein steers may be more susceptible to severe weather conditions than traditional beef breeds. During high heat, cold, wet, or windy conditions, steers may require extra mitigation and management to ensure their performance and intakes do not suffer due to weather conditions (Gant and Mader, 2010). With their increased frame size, steers require more bunk and waterer space and may require less head per pen later in their feeding program. During the feeding period, the utilization of growth promoting technologies are beneficial for optimal feedlot performance and efficiency of Holstein steers. Ionophores and anabolic implants are utilized in the throughout the feeding period and beta-agonists are utilized during the last 28 to 35 d (Duff and McMurphy, 2007).

When comparing performance of Holsteins to traditional beef steers, ADG, feed conversions, and DMI were similar but the beef steers were in the feedlot an average of 164 d compared to 289 d for Holsteins (Duff and McMurphy, 2007 and Zinn et al., 2016). Holstein have a greater mature weight and frame size compared to beef breeds and their composition of gain, at similar BW showed increased muscle mass and decreased fat (Gant and Mader, 2010). At the end of the feeding period, Holstein steers had a 16 kg advantage in live BW, similar HCW, and a 3% decrease in dressing percentage compared to beef steers. With their increased feed intakes, increased days-on-fed, and energy requirements for growth, Holstein steers tend to have an increase in metabolic disorders and metabolic deaths and may require extra attention during diet transitions (Gant and Mader, 2010 and Duff and McMurphy, 2007). The slaughter market for Holstein steers is not as stable or predictive when compared to the conventional beef breeds. With increased frame size and weight, carcasses from Holstein steers are longer, heavier, and may increase the wear-and-tear of machinery within harvest facilities (Gant and Mader, 2010). In the beef industry, Holstein steers have become a significant segment of the fed cattle industry due to their increased contribution to the demand for high quality beef. When managed correctly, feeding Holstein steers may be economically favorable for feedlot managers and will help the beef industry meet their product demands (Duff and McMurphy, 2007 and Zinn et al., 2016).

GROWTH PROMOTING TECHNOLOGIES

It is important for the beef industry to improve efficiency, productivity, and demonstrate the commitment of the industry to sustainability (Capper and Hayes, 2012). To improve efficiency, productivity, and sustainability of the industry, growth-promoting technologies (**GPT**) such as implants, ionophores, and β-agonists are utilized in several sectors, such as stocker and feedlot, where efficient growth is needed to increase profitability. The addition of GPT are proven to improve feed efficiency, live weight gain, decrease feed intake, and improve carcass characteristics (Arp et al., 2014; Brown et al., 2014, Bittner et al., 2017; Capper and Hayes, 2012). According to Capper and Hayes (2012), the removal of GPT from the industry, would increase the cost of beef by approximately 8.2%. This price increase would reduce profits and international exports while increasing competition among other beef producing countries. With the addition of GPT, animals are more likely to finish at a heavier weight earlier in life, produce a higher grading carcass while increasing profitability and decreasing inputs (White and Capper, 2013; Capper and Hayes, 2012). Growth promoting technologies used in conventional production systems result in a positive economical return, decreased environmental impact, and reduce inputs (Cooprider et al., 2011).

In a experimentaimed at quantifying the sustainability implications of feedlot production systems by comparing a conventional (**CON**) production system to a non-conventional (**NCON**) production system, Cooprider et al. (2011) found that NCON cattle required more resources than CON cattle. Without the utilization of GPT, NCON cattle required 42 additional days and 350 kg of additional feed to finish to similar BW as CON cattle (Cooprider et al., 2011). In Maxwell et al. (2015) compared a natural system with no GPT to a conventional system with inclusion of a βAA. With the addition of GPT, there was a 37.8% improvement in ADG and 33.3% improvement in efficiencies while maintaining similar DMI between systems. It was concluded through the experiment that cattle fed in a natural system may be fed past their optimal endpoint which drastically decrease efficiency and increasing may require inputs to get equivalent outputs as a conventional system (Maxwell et al., 2015; Cooprider et al., 2011).

Capper and Hayes (2012) studied the effect of the removal of GPT from the cattle feeding industry and found that an additional 385 head, 20,139 L of water, and 2,830 tons of feed are required to produce the same quantity of beef as a CON production system. The addition of GPT over the past years had resulted in a 34% increase in ADG, 21% decrease in cost of BW gain, and decreased the resources required to produce a quality beef product (Cooprider et al., 2011; Capper and Hayes, 2012). In addition to increasing production, GPT have potential to reduce carbon by 9.8% and fossil fuel use by 7.6% (Capper and Hayes, 2012; Cooprider et al., 2011). Over the past 50 years in the U.S., beef outputs have almost doubled whereas the beef cattle population has increased by 3%. Increased outputs have been achieved by employing management practices and technologies to improve efficiency and reduce resources used (Cooprider et al, 2011). Research has proven that the addition of technologies in conventional systems to increase outputs of cattle while decreasing inputs to increase profits.

Beta - Androgenic Agonists

Beta-adrenergic agonists (**βAA**) have been approved for use in the U.S. for the improved rate of gain, feed efficiency, and increased carcass leanness when fed to cattle at the rate of 90 to 430 $mg \cdot hd^{-1} \cdot d^{-1}$ for the last 28 to 42 d prior to harvest. Currently, ractopamine hydrochloride (**RH**) is the only βAA approved for use by the U.S. Food and Drug Administration (**FDA**; Vogel et al., 2009 and Johnson et al., 2014). The main mode of action of a βAA is to partition nutrients towards protein accretion while decreasing protein degradation and fat deposition. Overtime, inclusion of a βAA increases efficiency, daily weight gain, and carcass weight (Eisemann and Bristol, 1998). The effect of RH on the performance of beef steer, heifers, and Holstein steers has been well established in previous years, although, increased knowledge on the mode of action and its effects on the endocrine system, is still being developed. Beta-adrenergic agonist increase the uptake of amino acids by specific muscles which increases fraction accretion rates, and decreases degradation rates (Quinn et al., 2008).

Skeletal muscle is unique in that the number of multinucleated cellular units and muscle fibers are fixed at birth and increased muscle mass is achieved through protein accretion (Johnson et al., 2014, Yang and McElligott, 1989, and Eisemann and Bristol, 1998). After feeding, βAA bind directly to membrane receptors located on the cellular membrane in skeletal muscle. The βAA receptors are a large family of G protein-coupled receptors that are present on all cells. Once the βAA receptor is activated, a sequence of secondary messenger events occur within the cell. After activation, an elevation in adenylate cyclase and the formation of cyclic adenosine monophosphate (**cAMP**) occurs and increased cAMP binds to protein kinase A and immediately phosphorylates it. Once it is phosphorylated, protein kinase A increases the release of several metabolic hormones that aid in the break-down of nutrients (Johnson et al., 2014). Beta-adrenergic agonist reduce adipose tissue accretion by the combined effects of inhibiting *de novo* fatty acid biosynthesis through the activation of hormone sensitive lipase. After its activation, hormone sensitive lipase then partially hydrolyzes triglycerides and phosphorylates acetyl-CoA carboxylase, inhibiting the synthesis of fatty acids. After *de nova* fatty acid synthesis is inhibited, the cell then partitions the nutrients to the synthesis of amino acids to aid in protein production and increase in skeletal muscle mass (Johnson et al., 2014 and Eisemann and Bristol, 1998). Previous research has discovered the mode of action of βAA but additional research is needed to determine if increasing the intake of desired nutrients would make the process more efficient and further improve the desired traits of the animal. When βAA bind to non-muscular cells it has been previously hypothesized that they lead to an indirect effect through the production of hormones and other growth factors (Yang and McElligott, 1989). Indirect effects of βAA include increased production of insulin, pituitary hormone, and increases blood flow to skeletal muscles. It has been hypothesized that the main mode of action of βAA is to induce muscle hypertrophy through stimulation of protein synthesis within the muscle. In growing pigs treated with a βAA, muscle α-actin synthesis increased by 50% and mRNA synthesis increased by 2 to 3 fold in skeletal muscle when fed for 21 d. Similar results were seen in veal calves treated with βAA, with a 55 to 70% decrease in protease activity in the longissimus dorsi muscle, 68% decrease in activity of calcium –activated proteinase inhibitor, and a 30% increase in muscle size (Yang and McElligott, 1989). Suggesting that once inside the cells, βAA may have an inhibitory effect on protease activity within the muscle.

Eisemann and Bristol (1998) hypothesized that when RH was fed to beef steers at 80 mg · kg DM^{-1} for 15 d, insulin sensitivity or insulin responses may be altered. At the start of the experimental period, there was a spike in blood glucose, insulin, and a decrease in blood urea concentrations that lasted approximately 7 d after initial treatment and decreased at a linear rate for the remaining of the βAA treatment period. This drastic change in concentration may suggest a change in the sensitivity of the βAA receptors for their desired substrates. The decrease in blood urea concentrations suggest that with βAA treatment, nitrogen retention may increase leading to an anabolic response within the muscle. A decrease in blood glucose could indicate the increase in energy demand by the metabolic processes within the muscle cells (Eisemann and Bristol, 1998). In steers treated with RH, oxygen use was increased in the skeletal muscles and decreased in the liver when compared to control steers. A decrease in liver oxygen consumption indicate that with the treatment of RH decreases energy-using processes in the liver and increases in the skeletal muscles. These results suggest that with the addition of RH to the diet of steers, nutrient partition and metabolism is increased in the skeletal muscle to accommodate the nutrient demand for amino acid synthesis. Although the direct mechanism of action of RH has been well researched, the indirect effects of RH and how they can be manipulated may need additional investigation (Eisemann and Bristol, 1998).

Performance, Carcass Characteristics, Behavior and Mobility

Since the approval of βAA, there has been extensive research in the technique, combination with additional technologies, and duration of feeding to improve performance and carcass yield in traditional beef cattle and Holstein steers. This research has been beneficial to producers, feedlot managers, and nutritionists to improve weight gain, efficiency, and carcass characteristics of cattle. In previous studies, the addition of βAA improved feedlot performance, increased carcass characteristics, and decreased carcass leanness (Brittner et al., 2017; Beckett et al., 2009; Quinn et al., 2008 and Vogel et al., 2009) and recently, there has been an increased interest in the effects of βAA on additional carcass characteristics such as tenderness and consumer sensory attributes. In addition to RH, zilpaterol hydrochloride (**ZH**) was previously approved for use in feedlot cattle. Due to a possible increase in welfare concerns, ZH was pulled from the market for further research in administration techniques and behavior. When comparing the efficacy of RH to ZH, anabolic effects of ZH are more pronounced than RH due to a difference in receptor type (Vogel et al., 2009). In comparison of the treatment of RH to ZH in feedlot Holstein steers, Brown et al. (2014) found a 3.0 kg increase in final BW, 0.13 kg increase in ADG, and a 3.9% increase in efficiency while maintaining similar feed intakes when ZH was included in the diet. When comparing carcass characteristics, steers fed ZH treatment had increased HCW by 7.3 kg, LM area by 4.8 cm^2, and dressing percentage by 1.3% compared to Holstein steers fed RH. Increased dressing percentage may suggest that the inclusion of ZH increases carcass gains at a higher rate than the inclusion of RH which may suggest a different receptor or increased efficacy (Beckett et al., 2009 and Brown, et al., 2014).

As previously described, after extended administration of a βAA effectiveness is reduced due to a decrease in responsiveness of the βAA receptors (Johnson et al., 2014; Eisemann and Bristol, 1998; Yang and McElligott, 1989). Effective duration of βAA feeding has been previously studied to determine when a reduction in efficacy occurs at the βAA receptor and when cattle should either be harvested or βAA removed from the diet (Eisemann and Bristol, 1998). Beckett et al. (2009) compared ZH inclusion for various durations in Holstein steers, similar performance and carcass characteristics were found, but as duration increased, yield grade and dressing percentage were seen with decreased marbling score, quality grades, and back fat. While increasing the duration of βAA feeding may seem beneficial from a gain and BW standpoint, it may decrease the value of carcasses through decreased lipogenesis and marbling. Brittner et al. (2017) fed RH to beef steers at 28- and 42 d and found that with increasing duration of RH feeding, performance and carcass characteristics did not differ. In Holstein steers, increasing the duration of βAA feeding was beneficial for improving feedlot performance, but those results were not seen in beef steers. Experiments similar to these are beneficial in determining the correct feeding duration to obtain the maximum profitability and efficiency. Future research in the effects of removing βAA on the mode of action would be beneficial in determine the exact feeding time may be beneficial in decreasing the loss in efficiency.

Carcass characteristics are also improved when RH and ZH is fed at different durations. Hot carcass weights were increased by 11.6 kg and 17.2 kg, dressing percentage by 1.5 and 1.4 %, and 8.5 and 5.1 cm^2 increase in LM area when ZH was fed for 20 or 40 d when compared to Holstein steers not fed ZH, respectively (Beckett et al., 2009). When comparing feeding RH for 28 or 42 d, HCW was increased by 3.9 and 5.5 kg, LM area by 1.6 and 0.2 cm^2, and did not influence dressing percentage in beef steers, respectively (Brittner et al., 2017). When feeding ZH, the percentage of prime carcasses decreased by 0.62 and 3.2% and a 7.9 and 11.7% increase in select carcasses when comparing the treatment of ZH for 20 or 40 d, respectively. This suggests the when βAA are fed maximum dosages, carcass characteristics are improved but carcass quality may suffer a muscle marbling decreases with increase protein accretion, and decreased fat synthesis. Brittner et al. (2017) had similar results with a 7.9 % increase in choice carcasses and a 7.2% increase in select carcasses when RH was fed to beef steers. Increased duration of feeding is beneficial in improving carcass characteristics and yields while producing leaner carcasses.

Increasing dosage has been extensively researched to determine if increasing dose increases performance or carcass characteristics. Vogel et al. (2009) 200 or 300 mg RH doses in Holstein steers. While no statistical differences were seen, increasing dosage decrease daily intakes by 0.41 kg and improved efficiency by approximately 5%. Similar results were seen with carcass characteristics when comparing increasing RH dosages (Vogel et al., 2009). In a similar study, Quinn et al. (2008) dosed RH at 200 or 300 mg to heifers and found a 0.5 kg reduction in DMI, similar daily gains, and improved efficiency by 7.8% with the increased dose. Similar to Holstein steers, the increased dosage of RH in heifers did not affect carcass characteristics (Quinn et al., 2008). Although increasing dosage may seem to improve performance, carcass characteristics were not affected. Increasing the dosage of RH may have similar repercussions as increasing the duration through decreasing the effectiveness of the βAA receptors. Future research would be beneficial to determine at what dose and duration the βAA receptors burnout, decrease efficacy, and decrease efficiency of the animal.

Additional carcass characteristics such as tenderness or consumer sensory attributes have become a growing interest. Steak tenderness can be determined through 2 methods; Warner-Bratzler shear force (**WBSF**) or Slice Shear force (**SSF**). According to the American Society for Testing and Materials (ASTM, 2011), WBSF and SSF are measured through mechanical device testing to determine meat tenderness through shear force measurements taken from cross-sectional or core samples. Measurements can be categorized into very tender, tender, or tough, based on their tenderness scores. To test the effect of aging on tenderness and to determine if increased aging effects tenderness, steaks can be sampled at 14- or 21-d postmortem. Currently, research on the effect of βAA is abundant and previous work has indicated a negative effect of βAA on beef sensory attributes including steak tenderness (Arp et al., 2013; Howard et al., 2014; Holmer et al., 2009; Martin et al., 2014). While the addition of βAA produces carcasses that are heavier and yield leaner meat, without appropriate management, some βAA can have a negative effect on meat quality, especially tenderness and may decrease profitability of the carcass (Holmer et al., 2009). In previous research, the addition of RH or ZH decreased steak tenderness by 5 to 15%, respectively, when it was supplemented approximately 28 d prior to harvest (Mehaffey et al., 2009). Although decreases in tenderness values were seen, differences in consumer overall acceptability or tenderness acceptability when comparing steaks treated with βAA to control steaks were not (Mehaffey et al., 2009).

Mehaffey et al. (2009), compared control steaks to steaks from treated with ZH for 20 or 30 d prior to harvest. After 14-d aging, steaks treated with ZH had increased WBSF and SSF values for 20 and 30 d when compared to steaks not treated with ZH. Although after an additional 7-d of aging there was a 10.4 and 11.7% decrease in SSF tenderness scores for steers treated with ZH for 20 and 30-d, respectively. Similarly, Holmer et al. (2009) found that Holstein steers fed ZH for 0, 20, or 30-d there was an increase in WBSF score as the duration of ZH treatment increased. When comparing ZH treatment durations, increasing duration had similar average values for WBSF. Similar to Mehaffey et al. (2009), when postmortem aging was increased for steaks from ZH treated steers, WBSF values decreased for all steaks. When comparing different steak cuts, ZH increased shear force for triceps branchii by 15% and for gluteus medius by 25% when compared to shear force of steaks from control steers. With the addition of ZH, the difference between fiber type and muscle size may have an effect on the shear force. The longissimus lumborum and gluteus medius are considered to be fast twitch muscles and may have been more responsive to ZH treatment, which may increase the WBSF values (Holmer et al., 2009). As mentioned before, Holstein steers make up a large part of the fed cattle population. With the addition of ZH or RH, an increase in carcass leanness is seen along with a increase in shear force.

For sensory attributes after 14-d aging, control steaks had higher tenderness, juiciness, and flavor scores than steaks from steers treated with ZH (Mehaffey et al., 2009). Steaks treated with ZH had a 12.5% decrease in juiciness score when compared to control steaks after 14-d aging and after 21-d, ZH treated steaks had a 5.4% in juiciness scores. The decrease in juiciness can be attributed to the decreased amount of intramuscular fat that is deposited due to the βAA treatment. B-agonists are generally thought to have a major effects on meat quality and composition and are known to increase percentage of protein while decreasing fat percentage over the carcass (Mehaffey et al., 2009). The duration of ZH treatment prior to harvest did not have an effect on tenderness or sensory attributes at 14- or 21-d postmortem aging. Based on the findings in the present study, increasing the postmortem aging duration of steaks treated with ZH may aid in removing any significant effect from treatment that may have been seen in the 14-d steaks.

In a similar study, Martin et al. (2014) treated Holstein steers with RH and ZH prior to harvest to determine the effects of each on tenderness characteristics of strip-loin steaks. The average number of total steaks was greater in cattle treated with ZH compared to control or RH. Steaks from cattle treated with ZH produced steaks with the heaviest total steak weight. In steaks from steers treated with a βAA, there were a greater percentage of steaks with a SSF <15.3 kg after 16-d of aging. After 23-d, βAA did not have an effect on SSF of steaks. In comparison of βAA, steaks from steers treated with RH had higher SSF values after 16-d and 23-d aging the greatest percentage of steers with a SSF < 20.0 kg when compared to ZH treated steaks. However, after aging for 23-d the percentage of ZH or RH treated steaks classified as tender improved by approximately 16% and regardless, the percentage of both RH and ZH tender steaks remained lower compared to control steaks. This suggests that the ability to age steaks for a minimum of 21-d will greatly enhance the proportion qualifying for a very tender designation (Martin et al., 2014).

Animal Welfare/Well-Being/Mobility

Due to an increase in consumer interest in farming practices and animal well-being in confined feeding systems, an increase in research on the effects of GPT on animal welfare and mobility has been seen. Consumers and producers are continuing to increase interest in learning additional information regarding animal welfare of species used for meat and fiber production (Lehmkuhler et al., 2014). Previously, the discussion of the impact of stress and mishandling on physiological and acute immunological responses that decrease performance, feed intakes, and efficiency of the animals. Additional work has been completed to monitoring changes in pro-inflammatory cytokines and metabolic markers to aid in elucidating an animal's response to stressors in their environment (Lehmkuhler et al., 2014). Gaining this knowledge on the effects of stress on acute immune response will increase intervention strategies that aid in mitigating stressors and their effects on health and performance. Recently there has been an increase in interest in the effects of severe environmental factors on animal well-fare, performance, and profitability. Beef cattle have the ability to adapt to changes in their environmental. However, rapid or extreme changes in the environmental conditions can increase stressors (Boyd et al., 2015 and Lehmkuhler et al., 2014). With the increase in interest in animal well-being, there is still limited research in the effects of βAA on not only animal performance but also behavior and mobility.

Lehmkuhler et al. (2014) suggest that altering animal handing techniques can be used to decrease animal welfare issues by decreasing stressors and decreasing excitable behaviors. The temperament of cattle is a fear-related behavior that has been proven to be influenced by animal handling techniques. Grandin (1993) states that reducing stress during handling provides benefits of both improving productivity of the animal in their home pen but also their welfare through processing. The degree of stress imposed on an animal during handing or restraint can vary greatly and depends on factors such as previous experiences, genetics, tameness, history, and skill of the handler. Previous research has shown that with an increase in mistreatment of growing cattle there is a decrease in normal rumen and immune functions putting the animal at risk for digestive upset and illness (Grandin, 1993, Lehmkuhler et al., 2014, Boyd et al., 2015). Previous research has shown that cattle that became agitated in squeeze chutes prior to transportation to packing facilities had higher weight loss, tougher meat, increased bruises and dark cutters. Dark-cutting meat had decreased moisture, increased lactic-acid, dark in color, and has a shorter shelf life and decreases the quality of the meat. Careful handling of livestock animals at slaughter plants helps preserve meat quality and cattle that are handled quietly have higher quality meat when compared to cattle mistreated (Grandin, 2001).

Hagenmaier et al. (2017) compared low-stress to high-stress handling of beef steers treated with RH for 28-d prior to harvest. Cattle that were handled in high-stress had an 11.0% increase in temperament scores > 1 compared to low-stress handling. After cattle arrived at the packing plant, high-stress handling cattle had a 15.7% increase in cattle with a temperament score > 1. In addition to increases in temperament scores, chute-exit scores, and cattle vocalization increased in cattle that were handled in high-stress conditions. When comparing the physiological response to handling, high-stress conditions decreased blood pH, blood glucose, lactate, cortisol, epinephrine, and norepinephrine concentrations. Cattle in high-stress handling had a 22.1 bpm increase in heart rate, 0.08ºC in rectal temperatures, and 2.5 rpm increase in respiratory rates compared to cattle in low-stress conditions. This data suggests that the increase in behavior and chute scores could be due to a combination of factors instead of the treatment or RH. These factors include HS, transportation, aggressive handling, increased muscling, and increased body condition (Hagenmaier et al., 2017). The treatment of RH did not have adversely affect mobility or behavior at the feedlot or at the packing facilities. The results from this experiment suggest that when cattle are handled in high stress conditions, especially after a 6 h transportation period, they are at a higher potential for developing metabolic acidosis. This experiment proves that regardless to treatment of RH, aggressive handling had detrimental effects on cattle welfare and increase metabolic issues that will decrease meat quality and profitability (Hagenmaier et al., 2017).

ENVIRONMENTAL MODELING INDEXES

Thermal Neutral Zone

The physiological responses of livestock animals to low and high temperature are often presented in a bidirectional continuum divided into several zones based on physiological response of the animal. Within the zone of thermal comfort an animal has an optimal experience of comfort in relation to the environmental temperature (Van Iaer et al., 2014) The thermoneutral zone (**TNZ**) is defined as the range of ambient temperatures (**AT**) that does not require regulatory changes in metabolic heat production or evaporative heat loss for an individual to maintain normal body temperature (**BT**; Kingma et al., 2012). If environmental temperature are outside of the animals TNZ, the thermoregulatory mechanisms fail to keep body temperature within the normal range and may eventually decrease the health status of the animal (Van Iaer et al., 2014). The TNZ range for an individual is influenced by many factors that include body composition, age, gender, and diet. Originally, the TNZ was developed for metabolic studies within human nutrition to evaluate how the environment affects metabolic processes. Eventually, research began to develop a TNZ for livestock animals to aid in management in various climates to optimize livestock production. Thermoneutral zone has been defined for various cattle types in feedlot, dairy, and pasture production systems (McGlone, 2010). Within the TNZ, an animal can maintain homeostasis through normal metabolic and physiological processes and do not require energy expenditure to maintain a homeostatic state (McGlone, 2010; Mader et al., 2002; and Caton and Olson, 2016).

To determine the TNZ for cattle, behavior was observed in cold and hot conditions and the range was determine based on certain heat and cold stress behaviors. Behavioral changes were observed throughout the year in various environmental conditions; including herd bunching, respiration rates, feed and water intake, and activity level. The TNZ range is 10 to 30 °C for new born calves, -15 and 28°C for feeder calves, -10 to 28 °C for mature beef cows, and -10 to 30 °C for finishing steers (Mader et al., 2002 and McGlone, 2010). When ET are above the TNZ, they fall into the upper critical level and the animal must dissipate heat to the environment in order to maintain homeostatic state. In severe cases, heat dissipation may be limited and the body temperature of the animal may rise to dangerous and extreme levels. When the ET is below the TNZ it falls into the lower critical level and the animal must increase metabolic heat production in order to maintain homeostasis.

For finishing steers, TNZ is going to vary based on their fat thickness and body weight. As those factors increase towards the end of the feeding period, the upper critical level for finishing steers may decrease approximately 5 to 10 ºC (McGlone, 2010). The dissipation of heat requires energy expenditure; thus, after long-term heat exposure can result in decreased energy available for gain, decreasing body weight and decreased efficiency of the animal. Diet influences TNZ in cattle as well, highly metabolizable feed ingredients, such as processed grains, may ferment at a higher rate and result in amounts of metabolic heat (Caton and Olson, 2016). The TNZ is a recommended range of comfortable exposure for cattle, it varies greatly depending on the geographical location, environmental conditions, and cattle type (Caton and Olson, 2016).

Temperature-Humidity Index

Development of thermal stress index for cattle should be based on biological factors and cattle behavioral changes are reliable indicators of heat load thresholds (Gaughan et al., 2008a). Climatic indices are usually associated with risk classes that reflect the effect of environmental factors on biological response such as body temperature, respiration rates, performance, and milk production (Van Iaer et al., 2014). Prior to the development of the environmental index, CCI, an index was developed based on the relationship of humidity to ambient temperatures. The initial goal of the temperature-humidity index (**THI**) was to assess the effects of different environments and geographical locations on human health. The THI is a single value that take into consideration the AT and RH relationship and adjusts the temperature according. Since its development it has been well utilized within the beef, feedlot and dairy industries to assess animal discomfort. Humidity, or water vapor concentration within the air is important because it determines the ability of an individual to utilize evaporation through lungs or skin to dissipate heat (Thom, 1959). Cattle have the ability to tolerate higher temperatures with low RH because they are able to dissipate heat into the environment. Higher temperatures paired with high RH decrease the heat gradient and ability to dissipate heat. Thus, when the THI value increases, the ability of the animal to transfer heat by evaporation decreases due to the degree of water saturation of the air (Davis et al., 2003 and Mader et al., 2006).

Temperature-humidity index values are categorized into stress thresholds based on the threat of heat stress (**HS**) for livestock that are located in high heat environments (Davis et al., 2003 and Mader et al., 2006). According to the Livestock Weather Safety Index (LCI, 1970) the thresholds are defined as; THI $\leq$ 74 is classified as alert, 74 < THI < 79 as danger, and 79 $\leq$ THI < 84 as emergency (Amundson et al., 2006). Similar to the CCI, when THI values are > 79 DMI behaviors of cattle is diminished and the efficiency of the animal decreases. The increased THI value indicates that the animal's ability to dissipate heat through evaporation is diminished resulting in increased body temperature, respiration rates, and decreased performance (Mader et al., 2006; Davis et al., 2003; and Schüller et al., 2013).

In dairy and beef cows, higher pregnancy rates are essential to ensure a profitable production system. Sometimes environment conditions do not effect pregnancy rates, but not always. Previously, Amundson et al. (2006) found a negative relationship between pregnancy rates and THI with the negative effects started when then THI was > 73. When the THI increased from 70 to 84 (alert to extreme), pregnancy rates decreased 45% in dairy cows and 33% in beef cows (Amundson et al., 2006 and Ingraham et al., 1974). Higher THI values indicate that the animal needs alternative methods to dissipate their excessive heat load and to aid in their comfort. A disadvantage of the THI is that it does not take into consideration the SR, WS, or pen surfaces into the discomfort of the animal (Mader et al., 2006). Feedlot steers with increased BW, fat thickness and are consuming large amounts of a high-energy diet are at the highest risk of experiencing HS issues (Mader et al., 2006). Management solutions that have been proven effective include increasing fiber content of finishing diets, feeding during cooler parts of the day, or decreasing solar radiation exposure (Mishra et al., 1970; Mader et al., 2006 and Arias et al., 2011). Arias et al. (2011) found that feedlot steers with increased metabolizable energy-intake during summer months, had increased heat production compared to steers on a high roughage diet. These results were especially evident when the THI was > 75.

The temperature-humidity index has its disadvantages, such as the lack of additional environmental conditions. Furthermore, there is no genotype adjustments, so it is assumed that all livestock animals respond the same to extreme environmental conditions (Gaughan et al., 2008a). Without the addition of SR and WS, the discomfort of the animal may be over looked because the THI may not be as extreme. The THI is lacking a cold stress component and is only utilized for HS conditions. Understanding the relationship between RH and AT is critical in efficient production of livestock. Management methods to increase efficiency and productivity may include alternating breeding and feeding to time when the THI is cooler. The development of a dynamic thermal index improved animal management during periods of adverse weather and takes into account the duration and intensity, or magnitude of animal exposure (Gaughan et al., 2008a).

Comprehensive Climate Index

The interaction of environmental factors influences the real-feel of environmental conditions. There are numerous indices from previous research and literature that attempt to characterize the interaction of environmental factors on the comfort of animals. Mader et al. (2010) developed a well-rounded environmental index that incorporates environmental conditions that livestock animals experience on a daily basis in both summer and winter months. The comprehensive climate index (**CCI**) was developed to create environmental thresholds that quantify the mathematical relationship between AT, solar radiation (**SR**), wind speed (**WS**), and relative humidity (**RHum**; Mader et al., 2010). The index takes into consideration the interaction of the factors with each other and adjusts the temperature based on mathematical equations. For livestock producers, the CCI can aid in management practices based on environmental conditions. When developing the index, Mader et al. (2010) composited environmental data from 9 separate summer periods that involved extensive HS conditions and 6 different winter periods with extensive cold stress.

As previously described, behavioral changes have been used to determine the effects of the environmental factors on livestock performance and well-being (Caton and Olson, 2014). Because DMI is driven by environmental conditions outside of the TNZ, it was utilized as a primary dependent variable to determine the effect of AT, RHum, and SR on an animals well-being. From several severe heat and cold stress events throughout the United States, 3 general algorithms were developed to determine the following relationships; 1) AT and RHum, 2) AT and WS and 3) AT and SR (Mader et al., 2010). To split the SR equation into its two main sources; direct and ground surfaces the relationship between surface temperatures and water intakes was utilized (R^2 = 0.71; Mader et al., 2010). Ground surface radiation can contribute to the heat load and discomfort of an animal and is utilized as part of the SR equation. Davis et al. (2006) found that when the surface temperatures were greater than BT, animals absorbed heat from the feedlot surface was greater due to the reversal of heat dissipation. The effects of SR differs for cold conditions when compared to hot conditions and the adjustment to temperature are slightly greater per unit of radiation for the coldest conditions (Mader et al., 2010).

Additional algorithms have been included to determine heat transfer that occur at different AT with the same WS. The effect of WS, was found to be similar for both cold and hot conditions and may not contribute as much to the model as originally thought. Although, there is a potential heat gain due to WS when AT is greater than body temperature. The algorithm was designed to account for body heat transfer that is associated with evaporation and radiation exposure. Effects of WS at a given AT varies when RH is included in the relationship, especially for animals utilizing evaporative cooling in hot conditions (Mader et al., 2010).

Mader et al. (2010) found a positive, linear relationship between CCI and DMI ($R^2 = 0.71$). Previously, Kreikemeier and Mader (2004) found heifers fed during a winter season had a higher DMI than heifers fed during summer months indicating that climate effects DMI. Boyd et al. (2016) found similar results with a negative relationship between DMI and CCI value for summer months and a positive relationship in the winter months. Such knowledge can be useful altering feed and mitigation management strategies depending on the daily CCI value (Mader et al., 2010; Davis et al., 2003; and Mader et al., 2006).

Environmental factors combined with livestock behaviors stress helped to characterize livestock discomfort in hot and cold conditions and create a set of stress threshold (Mader et al., 2010). Ruminant animals a higher capacity for coping with cold environmental conditions than hot conditions, therefore, the magnitude between threshold levels may vary more for HS conditions. For HS the bottom end (mild) starts at 25 and increases by 5°C to the upper end with values > 45 (extreme danger). For CCI values in the extreme to extreme danger threshold, there is a higher probability for livestock discomfort and death. This is especially true for finishing cattle. Stress thresholds are recommendations and need to be shifted based on genetic composition, age, diet, susceptibility, fat thickness, coat color and size of the animal.

Obtaining an apparent temperature for assessing a continuous range of temperature, hot and cold, will benefit in projecting potential effects of climate change. With the addition of the CCI, a better estimate of environmental related energy expenditures can be developed that are not based on AT alone. The CCI has the potential to for use in assessing environmental effects on animal health, comfort, welfare, maintenance, and productivity (Mader et al., 2010).

HEAT STRESS

Heat stress is a major source of production loss in the dairy and beef industry and new knowledge about animal response continues to be developed to reduce the impact of climate on animal productivity and welfare (Nardone et al., 2010). In dairy cattle, the high heat can negatively affect milk production and reproduction rates due to decrease feed intakes, increased BT, and energy maintenance demands. This is because the TNZ shifts to lower temperature as milk yield, feed intakes, and metabolic heat production increases, especially when comparing high producing to low producing cows (Nardon et al., 2010).

Similarly, high producing feedlot cattle may experience the same discomfort with increasing environmental conditions due to increased body composition, heavier coats and darker coat colors. Nardon et al. (2010) reported that when environmental conditions were > 30.0°C, adverse effects were recorded on daily weight gain, reduction in daily DMI, carcass weight loss, lower fat thickness, and increase in disease has been reported.

Body Temperature Monitoring

Core body temperature (**CBT**) can be measured in one of three ways, ruminal, rectal, or vaginal. Previous research has also developed peritoneum, epidermis and sub dermis, but those methods are not proven effective with increased environmental conditions because location relative to exposure to environmental factors (Reuter et al., 2010). With current research, the method of measure CBT with infrared imaging of the eye and muzzle had also been tested (George et al., 2014). Effective CBT monitoring methods are effective in identifying illness and animals susceptible to HS. Although, these methods maybe practical in a research setting they may be unpractical in commercial feedlots and operations.

Rectal temperatures have been utilized to assist with the diagnosis and treatment of diseases in cattle. The disadvantage to monitoring ReT is the movement of cattle through a squeeze chute to obtain the temperature, which may increase CBT, and be detrimental if the animal is sick or experiencing HS (Reuter et al., 2010). To address these problems, temporary devices was developed to continuously record ReT to reduce cattle movement, labor, and stress. When continuously measuring ReT the changes in BT are observed and are potentially beneficial to determine HS or sickness before moving the animal out of the pen (Reuter et al., 2010). Ruminal temperature has been used to monitor CBT based on a small bolus being placed in the rumino-reticulum that transmit continuous readings. Using RuT for a measurement of CBT has previously been criticized because of the direct influence of fermentation and water intake may vary temperature recorded. Wahrmund et al. (2012) and Rose-Dye et al. (2011) monitored RuT and ReT on steers throughout an acidotic challenge and found a positive correlation (R^2 = 0.79) between them. Previous research in dairy cows found that continuous reticular temperature monitoring was effective in monitoring HS, milking times, and water intake (Ammer et al., 2016).

Stage of Production - Cow

Body temperature in beef cattle fluctuates throughout the day and can influence eating behavior, energy expenditure, production rates, and well-being (Mader, 2014). Body temperature in cattle can be detrimental if not correctly managed throughout the year. As previously stated, this is especially true in extreme heat or cold conditions. Diurnal variation of BT is dependent on time of day, health status, ET, environmental conditions, and feed and water intake. In several studies, beef cows minimum BT has been seen between 0300 and 1115 h, maximum between 1900 to 2115 h, and averages between 1100 to 1600 h daily (Lammoglia et al., 1997 and Cooper-Prado et al., 2011). When cows were exposed to greater AT, rectal (**ReTemp**) and rumen temperature (**RuTemp**) were highest in p.m. than in the a.m. and the maximum RuT is approximately 2 to 5 h after maximum AT exposure (Boehmer et al., 2015). A major problem of cow performance under heat load conditions is limited capacity of heat exchange between the animal and the environment. The possibility that the cow during the dry period being more sensitive to HS is sometimes ignored. Previous research has suggested that the endocrine system during this period is more sensitive to moderate to severe HS than during lactation (Adin et al., 2009).

According to Caton and Olson (2016), BT is maintained through heat dissipation and metabolic heat. When the ET are above the upper critical temperature, BT increases and decreases productivity through reduced feed intakes, and pregnancy rates. Elevated BT increases metabolic rate and energy expenditure. Over an extended period, elevated BT may alter metabolism of carbohydrates, lipids, proteins, and increase the maintenance requirements (Caton and Olson, 2016). When ET are below the lower critical temperatures, heat production from fermentation and metabolism may not be enough to maintain a normal BT (Caton and Olson, 2016). As a result, metabolism and behavior may have to compensate to provide heat to the body, influencing maintenance energy requirements. Constant BT monitoring in production settings would be beneficial in improving pregnancy rates and calving, but may not be ideal outside of a research setting. In dairy and beef cows, BT is utilized as an indicator of estrous or parturition (Lammoglia et al., 1997 and Cooper-Prado et al., 2011). Environmental temperatures and conditions have an impact on BT fluctuations around estrous and parturition. In previous research, Lammoglia et al. (1997) found a decrease in ReT approximately 48 to 8 h before calving. At lower ET, the magnitude of BT decrease could be more. This suggests that ET had an influence on the magnitude of BT drop. In addition to ET, body composition and age of the cow could influence BT fluctuations (Lammoglia et al., 1997). In previous research, Boehmer et al. (2015) found a positive relationship between AT and RuT when comparing the RuT of cows housed in warm versus hot environments. Similarly, Adin et al. (2009) found an increase in ReT of HS cows in a dry period. Cows that received evaporative cooling measures had 0.3 to 0.5°C decrease in daily average temperatures and a 40% decrease in RR when compared to cows in HS conditions.

Cooper-Prada et al. (2011) found similar BT fluctuations when monitoring RuT in beef cows before, during, and after estrous. Eight-hours prior to the onset of estrous, RuT increased approximately 0.42°C, 4 hr prior increased 0.52°C, and at the time of estrous increased 0.61°C. Handling occurred during late winter to early spring and ET would not have affected RuT at the time of estrous (Cooper-Prada et al., 2011). In a corresponding study, Wright et al. (2014) found that cows exposed to summer conditions in mid- to late-August, their RuT change was affected by the environmental conditions. Cows exposed to ET > 32.0 °C had increased RuT compared to cooler environmental conditions (Wright et al., 2014 and Boehmer et al., 2011). These previous studies suggest that RuT monitoring of beef cows can be used to accurately predict estrus within a few hours when ET are < 32 °C (Lammoglia et al., 1997; Cooper-Prada et al., 2011; Wright et al., 2014 and Boehmer et al., 2011). In previous research, cows that had a BT > 40 °C had a 5% conception rate compared to a 55% conception rate when BT < 39.8 °C (Boehmer et al., 2011). Increased BT impairs reproductive performance during summer weather because of failed ovulation, failed implantation, and possible fetal abortion (Amundson et al., 2006). This data suggests that initiating breeding period in a cooler season may increase pregnancy performance and decrease BT.

Stage of Production - Feedlot

Feedlot cattle typically have increased body composition and surface area that has potential to contribute to BT, especially at the end of the feeding period. Fat thickness, ruminal fermentation, and increased surface area influences BT and elevated BT in feedlot cattle can have negative effects on animal production, such as reduced intakes, increased respiration, and decreased animal comfort (Mader, 2002). Cattle finished during summer months need to be provided mitigation to ensure they are able to dissipate their excess heat to reduce heat load, decrease discomfort, and increase productivity. In periods of high-heat feedlot cattle must depend on non-evaporative and evaporative cooling to reduce their overall heat load. These additional methods include convection, conduction, and radiation, evaporative cooling from skin and respiratory surfaces. Non-evaporative cooling methods require a heat gradient to be successful. Heat gradients require that the environment surrounding the animal is cooler than the hide of the animal in order for heat transfer to be beneficial. The effectiveness of evaporative cooling is also reduced due to environmental factors such as wind or humidity that may limit the movement of vapors (Gaughan et al., 2008). Gaughan et al. (2010) compared BT of feedlot cattle housed in shade and no-shade pens in a high-heat environment and found that cattle house in shaded pens had increased performance, efficiency, and DMI compared to cattle in no-shade pens. During extreme heat waves, BT of shaded cattle were 0.96 °C cooler than non-shaded cattle and No-shade cattle reached a maximum BT within 2 d of the heat wave, whereas shaded cattle reached their maximum 3 days into the wave (Gaughan et al., 2010). In a similar study, Boyd et al. (2015) found similar BT and performance between shaded and non-shaded cattle in mild summer conditions in Nebraska. In a large pen feedlot study, Hagenmaier et al. (2016) found that the addition of shade increased DMI, decreased open-mouth panting, and proved shade to be an effective method to reducing discomfort in feedlot cattle in high-heat environments. These results suggest that the addition of shade may prolong accumulating heat load of the animal and may provide a means to dissipating heat to their surroundings.

Previous research has shown that BT is an effective method to measure the heat load of cattle, however, in a feedlot setting; it is unpractical due to increased cost, stress, and movement of the animal (Mader, 2002). By using a combination of observed local climatic conditions and animal responses, feedlot managers will be able to implement strategies to reduce the impact of severe hot weather conditions (Gaughan et al., 2008a). Respiration rates (**RR**) have been proven to be function of increased heat load and body temperature of the animal can be used to assess severity of heat load an animal without the additional stress associated with movement out of their home pen (Gaughan and Mader, 2014). A direct relationship between RR and environmental thermal heat load have been previously researched and determined that RR is a good visual indicator for determining difference in thermal tolerance between animals within a pen when BT cannot be continuously measured (Gaughan and Mader, 2014). In addition to the observation of RR, a panting score (**PS**) system was developed for a quick assessment of cattle behavior without counting individual animal's RR. Based on the animal's behavior, a four point scale was developed and recent research has developed a BT and RR threshold for each score. Instead of continuous BT monitoring, panting scores have been used to evaluate heat load status and are a reliable indicator of heat load of the animal (Gaughan et al., 2008a). A PS of 1 indicates mild stress characterized by slight panting, 2 indicates moderate stress characterized by fast panting and no open mouth, 3 indicates severe stress characterized as open mouth panting, and 4 indicates extreme stress characterized by open mouth with tongue fully extended and excessive drooling (Gaughan and Mader, 2014). For PS of 1 or 2, RR has been observed between 53 and 96 bmp and BT between 39.8°C and 40.4°C, a PS of 3 to 4 RR is between 132 and 123 bpm and BT is between 41.4 to 41.8°C (Gaughan and Mader, 2014).

With the addition of shade to feedlot cattle is not only beneficial for reducing BT but also reducing RR and PS. Boyd et al. (2015) reported that with even with the absence of an extreme heat wave, shade was effective in reducing average and maximum BT, RR, and PS. Without the addition of shade, BT and RR can raise to dangerous levels, increase energy expenditure, and reduce energy for efficient weight gains. Hagenmaier et al. (2016) reported that a slight increase in respiration rate can increase maintenance energy expenditure by approximately 7% and severe, labored, open-mouth panting can increase energy expenditure by approximately 11 to 25%. Panting has been previously categorized into two main phases by Gaughan and Mader (2014); 1) rapid shallow breathing and 2) deep breathing with reduced respiration rates. During a 10-d HS study, first phase was characterized by an increase in RR as PS increased from 0 to 2.5 and a decreased as PS decreased at 3 to 3.5. A decrease in RR is a change to deeper or second phase breathing and is not an indicator that the animal is coping with their heat load, but rather, the opposite is true. A combination of factors may cause a shift in breathing type including, increased BT do to an inability of respiratory cooling to reduce BT, increased external and internal heat load, and increased blood pH, and decreased pCO_2 (Gaughan and Mader, 2014).

Nighttime recovery is an important element when assessing the heat load status of feedlot cattle. If nighttime conditions are not taken into consideration, the heat load status of the animal may be over looked (Gaughan et al., 2008a). If the environmental temperatures are, hot for several consecutive days and nighttime temperature, do not cool, than cattle are at a higher risk of carryover heat load. A visual indicator of daily heat load carry over would be increased early morning RR and PS, before the heat of the day. Gaughan et al. (2008) compared nighttime sprinkling to day time sprinkling for feedlot steers housed in unshaded feedlot pens during an extended high-heat event. When steers were sprinkled during the hottest part of the day, their ReT were 0.52°C higher than steers sprinkled at night after the sun had set. After sprinkling during the day, both ReT and RR of steers increased regardless to the decrease in the THI. This indicated that after sprinkling on a hot day, the heat load of the animal may continue to increase possibly because while the sprinklers were running, the animal did not have to invoke a physiological response to cope with the hot conditions (Gaughan et al., 2008). Respiration rates followed a similar trend as the daily ReT, although, they had a 1 to 2 hour lag time in their peak compared to the ReT peak. The lag in time may suggest that the heat load of the animal must over load the dissipation mechanisms before the animal must resort to increased RR to dissipate excess heat (Gaughan et al., 2008). During the experimental period, the THI value was > 72 and did not fall below the alert threshold to allow sufficient cooling during the day or overnight. If steers lack the ability to regain normal BT overnight, may lead to increased heat load starting into the following day decreasing their ability to cope with the hot day. The results of this experiment suggest that nighttime cooling of feedlot steers experiencing HS during an extended period of time is effective in reducing their BT, RR, and maintaining DMI because it allows them to dissipate their excess heat prior to the start of another hot day. However, it does not address the issue of animal welfare and discomfort during the hottest part of the day (Gaughan et al., 2008).

The effect of shade on performance of feedlot cattle has been well reported (Hagenmaier et al., 2016; Boyd et al., 2015; Davis et al., 2003; Mader, 2002). Hagenmaier et al (2016) found as much as a 7.2% increase in G:F 0.2 kg/d increase in feed intakes when shade was provided in a commercial feedlot. With greater heat loads, fluctuations in feed intakes has been observed. On the day of extreme heat, DMI may remain constant for both shaded and un-shade but decrease on the subsequent days due to carry-over heat loads (Hagenmaier et al., 2016; Gaughan and Mader et al., 2014; Mader, 2002). The research suggests that providing cattle shade during extreme heat waves is beneficial for increasing performance, decreasing BT and RR, and increased well-being.

In extended heat waves, there may several days in a row with extreme environmental conditions that may aid in increasing BT, RR, and panting of cattle that are not provided a heat mitigation management. Nighttime cooling has proven to be an effective way for cattle to off load their excessive heat load. Overnight, there is reduced exposure to solar radiation and in most cases, decreased AT. Although, if the AT does not decrease, nighttime cooling may not be effective in reducing the heat load but may hinder it. Hagenmaier et al. (2016) stated that if the nightly THI is greater than 70, cattle will not be effective in reducing heat load overnight and could carry-over excessive heat into the following day. When daily and overnight adequate heat abatement fails to occur, increased panting in the AM is observed. It has previously been proposed that increased panting 1 to 2 hr prior to sunrise is an indicator of cattle trying to recover from the previous days heat load (Gaughan and Mader, 2014; Mader, 2002; Hagenmaier et al., 2016). Cattle with accumulated heat load will attempt to reduce heat load when AT are lower, resulting in over compensation of heat loss and lower BT leading into the following hot day (Gaughan and Mader, 2014). This research suggests that AM observation of cattle is beneficial in identifying cattle that may be susceptible to HS prior to the heat of the day.

Previous studies have manipulated the type of diet, level or energy, type of energy, and amount fed to feedlot cattle to decrease their heat load and susceptibility to HS. Feed management may be the least cost effective way to manage the well-being for cattle being housed in open aired pens exposed to extreme summer conditions. Limiting energy intakes can effectively decrease basal metabolic heat production and decrease total metabolic heat production of cattle exposed to high ET (Mader and Davis, 2004). When cattle are restricted to reduce BT, there are acute effects that could be taking place to reduce heat production. With decreased intake, there is a decrease in substrates for metabolism to take place within the body, which in the long term may affect efficiency and productivity. Long-term effects such as a reduction in organ size may take place (Davis et al., 2003). Increasing intakes in feedlot cattle is the ultimate goal, but if it is possible to increase energy level of the feed, the same effect may be achieved.

Feeding cattle later in the day may shift the combination of metabolic and environmental heat load to later in the day or evening. Arias et al. (2011) predicted that diluting high-concentrated diets with fiber during extreme heat waves is an altercation that may aid in keeping cattle on feed while decreasing their BT and overall heat load. Body temperature was lower and DMI increased when calves were fed a high-roughage diet, low-concentrate diet, compared to a low-roughage, high-concentrate diet during a high-heat event. Davis et al. (2003) had similar results in heifers fed high roughage diets. They found that BT, respiration rates, and oxygen consumption was reduced when the heifers were fed an 80:20 concentrate to forage diet. Suggesting that heat production is higher for high-energy diets and may aid in increasing BT in extreme heat waves, compared to high-roughage diets. A simple change in feeding time or diet type may aid in reducing an animals heat load while maintaining their feed intakes.

Effects on Metabolism

After extended exposure to high-heat conditions, susceptibility to HS may decrease and acclimation may increase among some animals. Acclimation is a phenotypic response developed by the animal to an individual source of stress within its environment. The acclimation of HS animals to meet thermal challenges results in the reduction of feed intake, increase in water intake, and alteration of metabolic functions that are linked with impaired health and efficiency (Nardone et al., 2101). Heat stress is thought to increase maintenance requirements of non-ruminant and ruminant animals due to decreased energy intake, increased respiration, and BT regulation. When environmental temperatures are below or above threshold values, efficiency of the animal is compromised because nutrients are diverted to aid in dissipating overall heat load and decreasing the BT of the animal

(Baumgard and Rhoades, 2012). Although it is difficult to quantify, it has been estimated in lactating dairy cows experiencing HS, maintenance is estimated to be increased by up to 30%. During periods of moderate to severe HS, limited adipose tissue mobilization prevents HS animals from employing glucose sparing mechanisms normally enlisted to maintain milk or skeletal muscle synthesis during periods of decreased intakes (Baumgard and Rhoads, 2012). Heat stress decreases feed efficiency and depending on severity, may increase oxidative stress to harmful levels within the animal. Feed efficiency has been shown to be negatively affected by increased oxidative stress caused by mitochondrial dysfunction (Russel et al., 2016). Mitochondria's main function is to provide the animal with energy by breaking down substrate molecules (i.e. glucose, fatty acids, or glycogen) and it consumes approximately 90% of the cells oxygen with a 2 to 4% reduction of reactive oxygen species (Baumgard and Rhoades, 2012 and Russel et al., 2016). Oxidative stress occurs when reactive oxygen species and other free radicals have exceeded the detoxification or antioxidant capacity of an enzyme and/or cell and may led to cell apoptosis. Energy efficiency is decreased with increase oxidative stress and unwanted by-products are produced from lipid peroxidation and protein oxidation (Russel et al., 2016). Understanding free radical and oxidant production within the cells may eventually lead to the effect of HS on carcass characteristics including carcass quality and tenderness. Additional research is needed to determine the rate of free radical production in ruminants experiencing extended periods of HS.

Extensive research has been completed to determine the effects of HS on performance, productivity, and well-being of cattle. Recently, there has been an increased interest in the metabolic and biochemical changes that occur in cattle during extended heat exposure (Rhoads et al., 2013). While cattle are in a hyperthermia state, cell survival is dependent on a family of proteins called heat shock proteins (**HSP**; Rhoads et al., 2013 and Gaughan et al., 2014). Heat stress proteins are activated in response to stress that include, heat, physical strain, and oxidative stresses. The main goal of HSP is to act as a 'chaperone' by stabilizing proteins by aiding with correct folding or refolding repairs that may have occurred within the cell. If the cell is damaged from extended heat exposure and cannot be repaired by an HSP, cell death via heat-induced apoptosis occurs (Rhoades et al., 2013). In an experiment by Rhoads et al. (2013), they saw a 4-fold increase in HSP production when cattle were exposed to environmental temperatures > 35°C. After 120-d of exposure to extreme HS conditions, production of HSP decreased. This decrease may indicate that an animal's susceptibility to HS may decrease.

As outlined previously, when ET increase, DMI decreases in feedlot cattle, dairy cattle, and beef cows. When experiencing HS, enter into a negative energy balance (**NEB**) that decreases their rate of production because of the lack of adequate nutrient intakes (Baumgard and Rhoads, 2012). Early-lactating beef and dairy cattle are mostly like to experience NEB because they are unable to consume enough nutrients to meet maintenance and milk production requirements and begin using nutrient stores. During NEB there is an increase in non-esterified fatty acid (**NEFA**) concentration exported from adipose tissues.

This increase occurs through accentuating the lipolytic response to β-adrenergic signals and inhibiting insulin-mediated lipogenesis and glucose utilization (Baumgard and Rhoads, 2012). When concentrations of NEFA and NEFA-derived are increased, high ketones blood concentrations are typically seen in cows in early lactation because fatty acids are a significant source of energy and precursors for milk fat synthesis during NEB. Previous research has shown a positive relationship between severity of NEB and NEFA concentration, tissue uptake, and oxidation (Baumgard and Rhoads, 2012). The magnitude of NEB and lipid mobilization explains why high-producing cows lose a significant amount of BW during early lactation.

WATER INTAKE

Adequate water intake is needed in all animals for normal metabolic functions, body temperature regulation, lactation, and reproduction (NASEM; 2016; Hicks et al., 1988). Due to the increase in concern for quality and quantity of water for human use, researchers' interest in water utilization by livestock has become increased. Extended drought conditions in certain parts of the U.S. have increased research to investigate the effects of drought on feed intake, performance, and over all digestibility of cattle in all sectors of the industry. Previous research has attempted to quantify water intake and its effects due to several factors. Factors that impact daily water intake include environmental, body conditioning, diet types and feed intake, water composition, water temperature, and seasonal timing (Winchester and Morris, 1956; Mullick et al., 1952; Utley et al., 1970;

Petersen et al., 2016). Daily water intakes (**DWI**) is considered to be quantitatively related to feed intakes in all ruminant animals and may affect nutrient digestibility, nitrogen retention, and blood urea concentrations (Utley et al., 1970). Water can be provided in one of three ways to the animal; 1) water consumption 2) moisture provided by diet (**FWI**) and 3) total water intake (**TWI**). Water consumption provides the highest concentration for the animal and represents the 'free water' drank by the animal and moisture provided by the feed and metabolic water provide the lowest concentration to the animal and the combination. For lactating dairy and beef cattle, the amount of water needed for milk production must be ingested in addition of water for other physiological needs (Utley et al., 1970).

The percentage of dry matter (**DM**) within the diet could play a factor in DWI. As previously stated, water can also be provided through moisture within the feed stuffs. In feedlot cattle that do not require high quantities of water daily, feed moisture is not as important. In lactating beef or dairy cattle, water requirements are increased due to the increased demand of milk production (Kume et al., 2010 and Adin et al., 2009). Water loss can occur through milk production, urine or fecal excretion, or sweat and vapor loss from the lungs. For high-producing dairy cows, require large amounts of water for adequate milk production without negative effects on health, reproduction, performance, or welfare. In dairy cattle, the importance or higher quality roughages is important for not only improved performance buy may also be an important water source (Kume et al., 2010). Kume et al.

(2010) found that increasing DMI increased TWI but DWI was not affected by increasing DMI suggesting that cows fed a silage feed ingredient did not seek out addition water. Increased DWI was also seen when the DM percentage of the diet increased but may have decreased TWI due to the lack of moisture in the feed stuffs. As acid detergent fiber (**ADF**) increased, both TWI and FWI also increased. Dietary crude protein or potassium were highly correlated with TWI while dietary potassium was correlated with DWI. As potassium and nitrogen intakes increased, daily urine production also increased indicating that increased DWI may be to aid in excretion of excess electrolytes to maintain blood and urine osmolality (Kume et al., 2010 and Adin et al., 2009). Understanding the composition of the diet and how the nutrients in certain feedstuffs influence TWI, FWI, or DWI may be beneficial in management of diet ingredients and diet formulations fed to high-producing dairy and beef cows.

Composition and Temperature

Water is the most critical nutrient for life and is required for all life processes. When water composition, temperature, or availability at altered, intakes may also be altered. Among other factors, water temperature holds the largest amount of variation (Brod et al., 1982 and Sexton et al., 2012). Water is needed for regulation of body temperature, reproduction, lactation, digestion, elimination of water, metabolic pathways, and mineral balance (Petersen et al., 2015; Petersen et al., 2016). As previously stated, daily water consumption and feed intakes have been found to be positively correlated. If water quality or quantity is limited, animal well-being starts to diminish and overall productivity starts to decline. The DMI and DWI relationship may be altered by the consumption of cold or hot water or frozen forage due to the transitory reductions in temperature of the ruminal contents (Petersen et al., 2016; Petersen et al., 2015). According to Ray (1989), early definition of water quality, or salinity, refers to the concentration of the major mineral elements occurring in water and does not consider other potential contaminants (algae, pathogens, pesticide or herbicides). The most common sources of water for cattle in either pasture or confined systems include ground water accessed through well, pond, spring or river water, or dams catching rain or snow. Depending on region of the U. S., will vary the concentrations of minerals and other contaminants seen within water sources (Petersen et al., 2015).

Determining the influence of water quality on steer feedlot performance, Ray (1989) compared intakes of water with different concentrations of total dissolved salts. Normal water, contained approximately 1,300 ppm total dissolved salts and saline water contained approximately 6,000 ppm TDS. The feeding period was broken into 2 56-d periods where steers were given either normal or saline water. When steers received normal water throughout the feeding period, their ADG and DMI were 9% higher and efficiencies were 4% higher than steers that received saline water during the experimental periods. Daily water intakes were not affected significantly affected by water quality in either summer or winter months (Ray, 1989). In comparison of performance of steers receiving normal or saline water throughout the feeding period, steers that received saline water in summer months had 13% reduction in daily gains, 11% reduction in DMI, but an 11% increase in efficiency. The increase in efficiency may be explained by the decrease in water intakes that may have decreased the particulate passage rate while increase microbial digestion within the rumen (Ray, 1989 and Petersen et al., 2015). Previously research has shown the water with 10,000 ppm of sodium chloride reduced weight gains, increased difficult and rapid respiration and incoordination in steers and heifers. Similarly, substantial reductions in live weight gain, incoordination, and death was observed in replacement heifers receiving 5,000 to 7,000 ppm soluble salts in their drinking water (Petersen et al., 2015 and Ray, 1989).

Considering water intakes, quality and mineral concentrations needs to be taken into consideration to ensure cattle health and well-being is not suffering. Geological location and precipitation may also play a factor in variating water quality. Petersen et al. (2015) compared water samples taken from three locations for 5 years in Montana; 1) north, 2) southeast, and 3) southeast of the Yellowstone River and samples were taken from flowing surface water, groundwater, reservoirs, and springs. In the present study, it was found that within the state, the three locations differed for each year, especially when comparing the sample source. It can be speculated that the difference in precipitation within a location can alter the concentrations of minerals within the water. In drier years, the lack of normal precipitation may have caused a concentrating effect and depending on the source of mineral dissolved in the water, concentration may have been effected by water run-off after drought conditions. For samples taken from ponds and reservoirs, mineral concentration did not differ due to settling, snow run-off, and lack of contact with mineral soils (Petersen et al., 2015). Depending on the source of water, yearly sampling may be beneficial in ensuring cattle are not consuming low quality water that may promote reductions in cattle productivity due to decrease intakes or mineral interactions, toxicities, or deficiencies (Petersen et al., 2015). Therefore, an important component of pasture management should be to provide cattle with good quality water (Lardner et al., 2013). Water quality testing of all water sources within a pasture prior to cattle exposure will ensure that consumption does not affect DMI, reproduction, or productivity. During drought situations, when reservoirs, streams, and springs are dry, cattle may be forced to utilize solute-concentrated ground water which may also impact productivity (Petersen et al., 2015).

Providing high-quality water to livestock will have benefits similar to providing a high-quality forages. Increased water intakes has a positive impact on greater feed intakes, improved health and immune response, and increased weight gain (Lardner et al., 2013). In some areas, artificial ponds are a common means of storing and supplying water for range cattle. Due to increased variability in dugout water quality, negative effects on animal health and productivity is a possibility. With increased surface runoff, ponds may become a source of organic contaminates including algae or pathogenic bacteria. Treating water to reduce contaminates and may include the option to add chlorine to oxidize and destroy pathogens (Lardner et al., 2013). When providing cattle an option to water sources, Lardner et al. (2013) found that cattle consumed more untreated well water than treated water in ponds. When comparing drinking behaviors, number of visits to the waterer was highest for untreated well water and least for highly treated or contaminated water. Although, it was also observed that steers divided their daily drinking among several sources during the first 10 to 20 of the first exposure, but the choice of water was not random. It may be suggested that cattle can detect differences between water types based on their properties of taste, odor, or appearance. Cattle may also be able to associate their intakes from certain water sources with a negative experience. For example, if a steer consumed water from a contaminated source and it caused a toxic or pathogenic response, then the animal may be able to discriminate against it based on a sight, smell, or taste (Lardner et al., 2013 and Petersen et al., 2015).

Environmental

The increase in DWI when environmental conditions are high may be attributed to the direct effect of the animal attempting to reduce their thermal heat load. As outlined earlier, evaporative cooling through increased respiration rates, may be the most beneficial means to reducing heat load but requires the animal to consume extra water to maintain homeostasis. Hicks et al. (1988) indicated that intakes were greater in July and August when ambient temperatures were highest and as ambient temperature increased 1°C, DWI requirements increased 0.22 L. The rate of water intake per unit of DMI remains constant when temperatures are between -12.2 to 4.4°C, but when above that, DWI increases with ambient temperatures at an accelerating rate. When temperatures are below that point, water intake if a function of DMI, when above that point, water intakes are a functions of environmental conditions (Hicks et al., 1988).

Arias and Mader (2011a) predicted that beef cattle in the U. S. consume approximately 760 billion liters of water a year. Environmental conditions can affect this amount significantly. As previously stated, long periods of high heat, summer conditions can have negative effects on cattle health, performance, and reproductive success. As previously stated, harmful environmental conditions paired with drought, can further decrease cattle intakes, efficiency, and well-being (Arias and Mader, 2011a and Davis and Mader, 2004). In high-heat conditions, generally DMI decreases and DWI increases. Arias and Mader (2011a) found a positive relationship ($R^2 = 0.60$) between ambient temperatures and increased water intakes of feedlot cattle. Mullick et al. (1952) found similar results when AT and RH were increased and the highest DWI was observed in the summer and spring months and least in the fall and winter months. When environmental temperatures were below 0ºC, water intakes plateaued while feed intakes increased and when ambient temperatures were above 10-15ºC, the opposite was seen. During the summer months, increased DWI can be attributed to the direct effect of the animal attempting to reduce the thermal load of cattle through perspiration. Thermal heat load can be mediated by evaporative cooling methods to decreased body temperatures to maintain homeostasis (Arias and Mader, 2011a and Mullick et al., 1952).

Adin et al. (2009) compared the water intakes of dry Holstein dairy cows in HS conditions to dry cows provided fans and sprinkling daily. Daily water intakes increased by 33.8% during the dry period and 38% during prior to parturition in Holstein cows that were housed in HS conditions compared to cows provided fans and sprinklers. In addition to increased water intake, daily milk yield, colostrum quality, calf birth weight, and milk protein also decreased in HS conditions. Cows that were not provided HS mitigation techniques could be using increased water intakes as a means of decreasing excess body heat production (Adin et al., 2009). In a experiment with similar objectives with feedlot steers, Mader and Davis (2004) wanted to determine if the time of day that pen surfaces were sprinkled with cool water had an impact on DMI, DWI, and water intake/ME intake (L/Mcal). During the hottest part of the experiment, pens were sprinkled for 120 min prior to the hottest part of the day (**AM**; 1000 to 1200) or during the hottest part of the day (**PM**; 1400 to 1600). When pen surfaces were sprinkled in the AM, DMI was similar but efficiency increased by 5.9%, DWI increased by 7.8%, and L/Mcal intake increased by 6.6% when compared to performance of steers in pens that were sprinkled in the PM. Sprinkling pens in the morning increased water intake of steers which may have played a large part in decreasing the carryover heat load and allowed the animal a chance to decrease it BT prior to the heat of the day. The two studies indicate that implementing mitigation techniques to cattle in HS conditions may decrease their heat load, while increasing their daily energy intake, daily gains, and efficiency (Mader and Davis, 2004 and Adin et al., 2009). In both studies, the increased water intakes could have a negative effect on efficiency and diet digestibility due to the increase in passage rates and decrease time digesta spends in the gastrointestinal tract (Adin et al., 2009).

With the trend in environmental changes that have been observed over the past 50 to 100 years, we have to expect that the livestock systems will be more effect by global warming then the industrialized system due to the lack of water's negative effect on crop production, pasture growth, and animal productivity (Nardone et al., 2010). The largest effect of climate on production system productivity has been seen in countries where the human demand for animal products is increasing due to continuous population growth. The efficiency of water usage within not only the beef industry, but the agriculture industry is going to be necessary to achieve sustainability through growing plants and animals that demand less water (Nardon et al., 2010). With the uncertainty of the future's environmental conditions, the possibility to produce twice the amount of animal products may become a large challenge due to the demand for water by each sector of the industry. The effort in selecting animals that are oriented towards robustness, adaptability to HS, and water restriction is going to the benefit the efficiency and sustainability of the system (Nardone et al., 2010).

Hoffman and Self (1972) investigated the effects of season, a shade structure, or stage of feeding period had an effect on water consumption. Results that were reported indicated a significant interaction between season and shade structure. When comparing non-shaded cattle in both season, in summer steers consumed 36.2% more water than non-shaded steers in the winter. Whereas, shaded steers consumed 42.6% more water in the summer than winter. The authors speculated that the interaction could be due to a greater rate of surface evaporation due to solar radiation in the non-shaded cattle, but only when the ambient temperatures were less than the hide of the animal (Hoffman and Self, 1982). The change in water consumption in winter is hard to explain, unless the shade structure trapped body heat and increased the CBT of the cattle. Additional research on cold stress on water intakes of beef cattle is needed. As average ambient temperatures increased, water intakes increased, regardless to body weight of the animal suggesting that environmental conditions play a larger role in water intake than body condition, ration type, or stage of production.

Drought

The escalation of drought associated with variable weather patterns may be limiting for grazing livestock due to reduction in livestock performance and production to due to HS, limited water availability, and reduced calving weights (Scasta et al., 2015). As previously stated, hot environmental conditions reduce voluntary feed intakes and increases maintenance requirements of ruminant animals. Certain breeds of ruminant animals that are more adapted to desert environments demonstrate a greater capability than non-desert breeds to adapt to stressful events caused by water deprivation paired with heat load (Silanikove, 1992). It has been previously predicted that the incidence of drought may increase in frequency, severity, duration, and persistence in the Northern Hemisphere and especially in the interior regions of U. S. (Scasta et al., 2015). During extensive periods of drought or water restriction, diet digestibility has been shown to increase due to the decreased passage rates and increased microbial exposure. In a review by Silanikove (1992) it has been predicted that cattle experiencing water restriction or HS their DMI decreased by up to 30% when compared to their baseline intakes. Water deprivation or HS in highly producing cattle (i.e. dairy cows) would results in a more acute reduction in feed intakes due to the increased rate of dehydration and high internal heat production. Utley et al. (1970) stated that water intake is considered to be quantitatively related to feed intakes in all ruminant animals and previous research has found a 2 to 4 kg of water to 1 kg of dry matter eaten. Previous research has found that with extensive water restriction resulted in higher digestibility coefficients for all nutrients due to increased retention time of feed within the rumen and increasing microbial exposure (Silanikove, 1992 and Utley et al., 1970). In addition to reduced feed intakes, water restriction decreased urine volume, nitrogen excretion, and improved nitrogen retention.

Utley et al. (1970) studied the effect of water restriction on eating behaviors, feed consumption, digestibility in steers fed a high concentrate diet. When steers were restricted

20% or 40% of their baseline intakes feed intakes decreased by 4.8 and 22.6%, respectively and water to feed ration decreased from 3:1 to 2.2:1 with 40% water restriction. Water restriction has shown to have an impact on salvia production in ruminants and may impact passage rate, rumen volume, and rumen environment. Restriction of water to beef cows in 24, 48, and 72 hr periods resulted in 40, 60, and 80%, respectively, reduction in resting salivary flow rate compared to cows with ad lib access to water (Arias and Mader, 2011a and Silanikove, 1992). Previous research has shown a positive relationship between reduced saliva production and net outflow of fluid from the rumen. The reduction of fluid movement across the rumen wall may be partially related to a reduction in blood perfusion of the rumen wall and the reduction of movement also influences absorption of nutrients for the animal.

Rumen Temperature

As previously stated, temperature monitoring devices that can be used remotely are beneficial due to the decrease in cattle movement, restraint, and stress that may impact CBT measurements. The impact of water temperature on RuTemp has been well researched. Bewley et al. (2008) monitored RuTemp in dairy cows through drinking events to quantify the length of time required for temperatures to return to the pre-drinking temperatures and the effect various water temperatures had on temperature changes. As water temperature consumed decreased, temperature change decreased as well with the largest change during consumption of cold water (7.6°C) RuTemp decreased 8.5°C. When cows received water that was similar to their CBT, RuTemp decreased slightly, but returned to baseline after approximately 15 minutes. Whereas, when receiving cold water, RuTemp decreased rapidly and slowly increased, but never reaching baseline temperatures. After consumption, ingested liquid is readily mixed with rumen contents resulting in the rapid decrease in temperature. Body heat is needed to warm to contents of the rumen back to a normal temperature, depending on the dilution of water to rumen contents, the magnitude of heat transfer may be minimal (Bewley et al., 2008). Rapid increases in RuTemp after water consumption indicate that the dramatic decrease is only temporary and at smaller quantities, may not impact the CBT of the animal. Further research in the effect of DWI on CBT of cattle, especially in heat stress conditions, would be interesting.

In sheep, Brod et al. (1982) reported a similar decrease in RuTemp after water consumption of several different temperatures. In addition to RuTemp, rumen digestibility and fermentation were also investigated. When consuming water at 0°C, RuTemp decreased by 6.44°C, digestion coefficients were lowest, and volatile fatty acid (**VFA**) fermentation was decreased. When sheep consumed water at 30°C, dry matter, protein, and fiber digestion increased by 1.9, 3.6, and 1.9%, respectively, when compared to water at 0°C. Similar to Bewley et al. (2008), the greatest change in RuTemp occurred when sheep consumed cold water and the magnitude of change decreased as water temperature increased (Brod et al, 1982). Although the phenomena of heat transfer within the rumen has been researched, the impact of extreme temperature changes on ruminant physiology is unknown. Limited research is available to determine the impact of water temperature and quantity of intakes on rumen microbial population, fermentation, and output of end products. It would be interesting to investigate if changing water temperature provide to cattle could change the end products of fermentation.

Predicting Water Intakes

Predicting water intake in cattle has proven challenging due to the vast number of factors that impact DWI. Environmental conditions, type of diet, animal breed, and animal BW, just to name a few. Estimates of DWI can assist feedlot cattle management by predicting daily use over a range of environmental conditions to ensure cattle had access to adequate water. These estimates are useful in ensuring adequate water is available for mitigating and minimizing HS in cattle (Arias and Mader, 2011a). Most equations incorporate environmental conditions, Hick et al. (1988) took a different approach by incorporating dietary salt intakes. When salt was included in the diet, daily intakes were 38.6 L and decreased by 11.9 and 8.4% when salt was included at 0.25 and 0.50%, respectively. The prediction equation predicted that water intake was lowest when dietary salt was 0.25%, but DMI was also decreased by 7.3% compared to 0% salt. The decrease in DWI may have been a function of the decreased DMI within the equation and not a function of salt level included in the diet (Hicks et al., 1988). As previously stated, DWI was greatest in July and August, when salt was increased in the diet at either 0.25 or 0.50%, water intakes differed by 0.14 L. Regression of the daily environmental conditions with predicted DWI indicate that maximum temperature was a major influential factor and dietary salt levels was not (Hicks et al., 1988). According to their predictions, feedlot cattle in summer months require about 38.0 L of water daily, regardless of dietary salt. When salt was included in the diet at 0.50% DWI tended to decrease (Hicks et al., 1988).

Sexson et al. (2012) used DMI, feeding behaviors and weather conditions to predict DWI of feedlot steers during the spring to summer months. A positive relationship was found between water intakes and all measure of temperature and as temperature, wind speed, and precipitation. As environmental conditions increased, specifically THI, DWI increased at a linear rate. Water intakes were also positively related to wind speed and wind direction. Indicating that as wind increased or changed from south to north, DWI increased. As mentioned before, the disadvantage of THI is the lack to additional environmental conditions included in the equation. In the final model, THI was not included. Sexson et al. (2012) did include BW into their model. As steer's BW increased from 300 to 500 kg, DWI also increased from 22 to 38 L. After 500 kg, DWI decreased. Towards the end of the feeding period, the proportion of fat in BW gain increases and the proportion of protein and water contributing to gain, decrease. Suggesting a decrease in DWI requirements, based on the change in physiological gain of the animal (Hicks et al., 1988; Sexson et al., 2012). In their final conclusions, DWI is a function of animal gains and several environmental conditions. Due to variability to feed intakes, it has been speculated that DMI has a smaller impact on DWI than previously indicated. Additional research is needed to determine the impact of concentrate and/or roughage levels on DWI of feedlot steers.

When predicting DWI of beef steers or dairy cows, individual observations is ideal to record individual intakes. Although, individual observations may change the temperament and bunk and/or water behaviors of cattle (Brew et al., 2011). Through advancements in technology, electronic feeders are available to obtain individual DMI and DWI while maintaining the group setting within the pen. Brew et al. (2011) predicted DWI to be 29.9 L based on individual intakes through an electronic system. Within the experiment, AT were within the TNZ of the animals and did not influence DWI. In comparison to other prediction equations, recorded intakes in Brew et al. (2011) were 28% less than Hicks et al. (1988) due to differences in the AT, facilities, and management practices. Within each equation used to predict DWI, there are flaws that add a different element of variation. While using a combination of the above methods paired with changes in RuTemp may be beneficial in fulling understanding DWI behaviors, diet influences, and changes in environmental conditions. The use of RuTemp in predicting DWI will be beneficial in ensuring adequate water is available for animals at all times.

SUMMARY

One of the biggest challenges facing the industry is cattle supply (Zinn et al., 2016). Research has helped increase our knowledge on individual challenges and how their impacts are intertwined. Understanding how to manage certain situations to decrease the stress of cattle is beneficial in increasing efficiency of the sector. The beef industry faces many challenges as consumer perspective, technology uses, and weather continues to change. As previously stated, increased exposure to environmental conditions has potential to have negative impacts on animal health, wellbeing, and productivity in all sectors of the industry. The use of technologies within the industry is an issue that will continue to be questioned by consumers (Lyles and Calvo-Lorenzo, 2014). The views of the consumer are a major influence on the success of the beef industry and their views need to be taken into consideration when managing cattle welfare and well-being properly. Environmental conditions are considered to be highly variable and sometimes unpredictable. Minimizing the impact of environmental conditions through heat mitigation techniques (i.e. shade, sprinklers, or fans) may be a chance to enhance animal welfare (Lehmkuhler et al., 2014). Utilization of untraditional beef cattle within the fed cattle sector is increasing. As previously stated, Holstein steers made up only 5.7% in 2000 and was over 15.9% in (2016 (Boykin et al., 2017; Garcia et al., 2008; McKenna et al., 2002; Moore et al., 2012). Although Holstein steers may have disadvantages, they may help the beef industry meet the growing demand to produce high quality animal proteins while making a profit.

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Running Head: *Holstein performance and carcass characteristics*

CHAPTER III

GROWTH, PERFORMANCE, AND CARCASS CHARACTERISTICS OF FEEDLOT HOLSTEIN STEERS FED RACTOPAMINE HYDROCHLORIDE

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ABSTRACT: Growth-promoting technologies such as implants, ionophores, and β-agonists improve feedlot performance, efficiency, and carcass characteristics of cattle. The objective of this experiment was to determine the effects of dose and duration of ractopamine hydrochloride (**RH**) on feedlot performance and carcass characteristics when fed to Holstein steers. A randomized complete block design was used with a 3 × 3 factorial arrangement of treatments with 3 RH doses (0, 300, or 400 $mg \cdot steer^{-1} \cdot d^{-1}$) fed for 3 durations (28, 35 or 42 d). Holstein steers (n = 855; initial BW = 448 $\pm$ 37 kg) were blocked by BW and randomly allocated to 1 of 9 pens (15 blocks; 9 dose × duration treatment combinations) approximately 72 d before harvest. Weekly pen weights, chute temperament scores and animal mobility were determined during the RH feeding period. At harvest, carcass data were collected on all steers, and tenderness was measured on steaks from 3 or 4 randomly selected steers from each pen. Slice shear force (**SSF**) was determined on a steak selected from each side of the carcass after aging for 14 or 21 d. With increasing RH dose, ADG and G:F increased linearly (P = 0.002) while BW gain increased linearly with RH dose and duration ($P \leq 0.003$). Hot carcass weight (P = 0.02) and LM area (P = 0.001) increased linearly with increasing RH dose. The percentage of carcasses in the USDA Yield Grade 2 category increased linearly (P = 0.008) and percentage of carcasses in the USDA Yield Grade 4 category tended (P = 0.08) to decrease linearly as RH dose increased. In the 14-d aged steaks, the percentage of steaks with SSF $\leq$ 15.3 kg decreased linearly (P < 0.001) while the percentage of steaks with $\geq$ 20.0 kg SSF increased linearly (P < 0.001) with increasing RH dose. After 21-d aging, there was a tendency (P = 0.06) for a higher percentage of steaks from steers fed RH to have SSF $\geq$ 20.0 kg (2% of total steaks), but no difference ($P \geq 0.12$) in the percentage of steaks with SSF $\leq$ 19.9 kg. Final chute temperament ($P \geq 0.45$) and animal mobility ($P \geq 0.67$) scores were not affected by feeding RH. Increasing the dose of RH (300 or 400 mg·steer^{-1}·d^{-1}) fed for 28 to 42 d before harvest increased ADG, G:F, HCW, and LM area when fed to Holstein steers with no negative effects on behavior or mobility. The percentage of steaks classified as not tender improved when steaks were aged for 21 d from steers treated with RH.

Key words: Beta adrenergic agonist, carcass quality, feedlot performance, Holstein steers, mobility, ractopamine hydrochloride

INTRODUCTION

Beta-adrenergic agonists (**βAA**) have been shown to improve feedlot performance and carcass characteristics of beef cattle when fed for 28 to 42 d before harvest. Ractopamine hydrochloride (**RH**; Actogain, Zoetis Parsippany, NJ) is a βAA that increases carcass leanness by increasing protein accretion and decreasing fat accretion. Ractopamine is to be fed at a rate of 90 to 430 mg·animal^{-1}·d^{-1} for the final 28 to 42 days of the feeding period to improve rate of weight gain, feed efficiency, and carcass leanness.

According to the National Beef Quality Audit (Moore et al., 2012; Boykin et al., 2017), the percentage of Holstein steers in the fed cattle market increased from 10 to 16% from 2011 to 2016. While demand varies depending on beef cow numbers, Holstein bull calves continue to be an integral part of the U.S. beef industry. Although information is lacking for Holsteins compared to beef cattle, the addition of growth promoting technologies such as implants and βAA provide a means to enhance meat production without decreasing meat quality.

Previous research has shown the addition of RH to the diet 28 to 42 d prior to harvest resulted in improvement in ADG, G:F, HCW, and carcass leanness (Arp et al., 2014; Brown et al., 2014, Bittner et al., 2017). However, research determining the effects of feeding RH at varying doses and durations in Holstein steers is limited. The objective of this experiment was to characterize feedlot performance, carcass characteristics, behavior and mobility, and muscle tenderness of Holstein steers fed RH at 0, 300, or 400 mg·steer^{-1}·d^{-1} for 28, 35, or 42 d.

MATERIALS AND METHODS

All animal care and management procedures for this experiment were approved by the Oklahoma State University Institutional Animal Care and Use Committee.

Cattle

Holstein steers were obtained in 2 separate groups from a commercial feedlot located near Happy, TX and transported 568 km to the Willard Sparks Beef Research Center (**WSBRC**) near Stillwater, OK. Group 1 arrived on February 6, 2015 (441 steers; initial BW= 454 $\pm$ 37 kg) and Group 2 arrived on September 9, 2015 (414 steers; initial BW = 438 $\pm$ 35 kg). Steers were used in a randomized complete block experimental design with a 3 × 3 factorial arrangement of treatments where RH was fed at 3 doses for 3 durations. Steers were blocked by BW and randomly allocated within block to 1 of 9 pens. Each pen within each block was then randomly assigned to 1 of 9 treatments. Ractopamine hydrochloride was fed at 0 (**CON**), 300, or 400 mg·steer^{-1}·d^{-1} for 28, 35, or 42 d before harvest. Group 1 had 7 blocks (63 steers/block; 21 steers/dosage; 21 steers/duration/block; and 7 steers/pen). Group 2 had 8 blocks (45 to 54 steers/block; 15 to 18 steers/dosage/block; 15 to 18 steers/duration/block; and 5 or 6 steers/pen).

Arrival Processing

Upon arrival, steers were collectively weighed on a pen scale to obtain an average BW and placed into 16 holding pens (25 to 27 steers/pen) that were 12 × 30 m. Pen were soil surfaced with 12 m of concrete fence-line bunk and a 75 L concrete fence-line water tank shared between 2 adjacent pens. Approximately 36 h following arrival, steers were individually moved through a squeeze chute where BW and hip height were measured and steers were identified with both visual and electronic identification (EID) ear tags. Steers were vaccinated with a modified-live viral vaccine (Bovi Shield IBR; Zoetis, Parsippany, NJ) to prevent bovine respiratory disease caused by infectious bovine rhinotracheitis and treated for internal and external parasites with fenbendazole oral anthelmintic (Safeguard; Merck Animal Health, DeSoto, KS) and a pour-on anthelmintic (Dectomax Pour-on; Zoetis). Steers were sorted based on the group's individual median BW into heavy and light pens and were returned to their holding pens (25 to 27 steers/pen) after processing.

Arrival Groups

On d 29 from arrival, steers within Group 1 and Group 2 were weighed individually, implanted with 40 mg of estradiol and 200 mg of trenbolone acetate (Revalor-XS, Merck Animal Health) and returned to holding pens. Due to a malfunction with a load cell on the chute scale, BW were not recorded for steers in Group 2. On d 31, all steers in Group 2 were weighed and individually and returned to holding pens. Steers were projected to a weight block from the d 29 (Group 1) or d 31 (Group 2) BW and final harvest dates were projected. Weight blocks were filled heavy to light and blocks were randomly assigned to 9 continuous pens located on either the south or north side of the feedlot. There were 64 treatment pens (32 pens/north and 32 pens/south). Block was randomly assigned to 9 pens located on either the north or south side of the feedlot. For the entire experiment, there were 6 blocks housed on the south and 9 blocks housed on the north. Steers were randomly allocated to 1 of the 9 treatment pens within a block and pens within a block/location were randomly assigned to 1 of 9 treatments. Upon allocation to their experimental pens, all steers received a colored ear tag unique to RH dosage. On d 30, all steers in Group 1 were sorted into their experimental pens. For Group 2, steers within a similar weight block were weighed individually 73 d prior to their projected harvest date. On d 72, all steers were sorted to their experimental pens.

Finishing pens were 4.5 × 15 m in area with a 4.5 m-long concrete bunk at the front of the pen. The pens contained a 4.5 × 4.5 m concrete pad, with the remainder of the pen being soil surfaced. The pens were under partial cover, with the bunk and pad being covered by an overhang. A 75 L concrete water tank (model J 360-F; Johnson Concrete, Hastings, NE) was shared between 2 pens and was cleaned 3 times/wk.

The experiment was designed with a minimum 28-d treatment pen adaptation prior to the start of RH. During the beginning of Group 1's experiment period, the feedlot received a high amount of rainfall. Due to deteriorating pen conditions, steers that had not begun their RH treatment period (the lightest four blocks) were moved to larger holding pens for approximately 21 d. Steers were penned by RH dose within block. A minimum of 14 d before the start of the RH treatment period for the 42-d duration steers, steers in each block were weighed, sorted, and returned to their original treatment pens.

Health Management

Steers were observed daily in the pens by a trained evaluator blinded to treatments. Steers were evaluated based on a modified DART system (Zoetis, Parsippany, NJ) with some modifications as described by Step et al. (2008). The subjective criteria used for pulling steers consisted of depression, abnormal appetite, and respiratory signs. Signs of depression included, but were not limited to depressed attitude, lowered head, glazed or sunken eyes, slow or restricted movement, arched back, difficulty standing or walking, knuckling of joints or dragging toes when walking, and/or stumbling. Signs of abnormal appetite included an animal that was completely off feed, an animal eating less than expected or eating slowly, a lack of gut fill or gaunt appearance, and/or obvious BW loss. Respiratory signs included labored breathing, extended head and neck (in an attempt to breathe), and/or audible noise when breathing. Steers were evaluate based on the 0 to 4 severity scoring system adapted from Step et al. (2008) and Wilson et al. (2016). The evaluators assigned a steer a severity score from 0 to 4 based on clinical signs and severity of those observed signs. A score of 0 was assigned for a calf that appeared clinically normal. A score of 1 was assigned for mild clinical signs, 2 for moderate clinical signs, 3 for severe clinical signs, and 4 for a moribund animal. For a steer to be assigned a score of 4, the steer had to be unable to rise, had to require assistance to rise, or had to have extreme difficulty standing, walking, or breathing. Steers with severity score of 4 required immediate attention.

The objective criteria used to determine if antimicrobial treatment was necessary was rectal temperature. All steers assigned a severity score of 1 to 4 were taken to the processing chute for rectal temperature measurement (GL M-500; GLA Agricultural Electronics, San Luis Obispo, CA), unless it was deemed necessary for a moribund steer to receive treatment in the home pen. Any animal that was identified with a severity score of 1 or 2 and had a rectal temperature of 40ºC or greater received an antimicrobial according to label instructions. If a steer was identified with a severity score of 1 or 2 and had a rectal temperature of less than 40°C, no antimicrobial treatment was administered, and the steer was returned to its pen after evaluation. Any animal with severe clinical signs (severity score = 3 or 4) received an antimicrobial according to label instructions regardless of rectal temperature.

Before antimicrobial administration, BW was obtained to calculate the appropriate dose. Antimicrobial doses were calculated by rounding the steer's current BW up to the nearest 11.3 kg. All antimicrobials were administered subcutaneously per manufacturer's label directions following Beef Quality Assurance Guidelines (NCBA, 2001). The first time BRD treatment criteria was met, tulathromycin (1.1 mL/45.4 kg BW; Draxxin, Zoetis) was administered. If a steer met BRD treatment criteria again > 10 d post Draxxin administration, the steer was treated with danofloxacin mesylate (2.0 mL/45.4 kg BW; Advocin, Zoetis). A steer that met the BRD treatment criteria for a third time (> 10 d post Advocin therapy) was treated with ceftiofur hydrochloride (1.5 mL/45.4 kg BW; Excede; Zoetis).

Steers pulled for other health reasons (e.g., lameness issues or pink-eye) were moved to the squeeze chute and evaluated by a trained individual. Steers were evaluated for lameness based on a 1 to 4 scale: 1 = slight lame; 2 = mildly lame; 3 = moderately lame; 4 = severely lame (Step et al., 2008). If the veterinarian deemed necessary, steers were treated subcutaneously with oxytetracycline (4.5 mL/45.4 kg BW; Bio-Mycin; Boehringer Ingelheim, St. Joseph, MO) and intravenously with flunixin meglumine (1.0 to 1.5 mL/45.4 kg BW; Banamine; Merck Animal Health, DeSoto, KS).

If steers were unable to continue due to health reasons before or during the experimental period, they were removed from their home pen, evaluated by a veterinarian and euthanized for humane reasons, if deemed necessary. All steers that died or were euthanized were taken to the Oklahoma Disease Diagnostic Laboratory at the Center for Veterinary Health Sciences for a complete necropsy.

Feed and Bunk Management

Receiving and finishing diets were formulated to meet or exceed NRC (2000) requirements (Table 1). Upon arrival, steers received 0.50 kg/steer of prairie hay and 3.2 kg/steer of the receiving diet. The following day, steers received 3.2 kg/steer of the receiving diet and 3.2 kg/steer of the finishing diet. Steers were transitioned to the finishing diet over a 7-d period by decreasing the receiving diet by 0.5 kg each day and adjusting the total feed delivered by increasing the finishing diet. Steers were fed twice daily at approximately 0700 and 1300 h. Feed bunks were managed to ensure trace amounts of feed were in the bunk before morning feeding. Each morning, bunks were cleaned to remove in-edible feed, manure, etc. Bunk dividers were installed in an attempts to ensure no cross contamination or cross feeding occurred. Feed was mixed and delivered in a 274-12 Roto-Mix mixer wagon (Roto-Mix; Dodge City, KS) with delivery accuracy to the nearest 0.50 kg. Feed refusal were removed from the feed bunk and weighed on weigh days, or if feed was wet, or if feed was more than 1-d old.

The finishing ration contained steam-flaked corn, dried distiller's grains plus solubles (**DDGS**), alfalfa and prairie hay, liquid feed fat, and dry supplement (Table 1). The dry supplement was pelleted and contained ground corn, wheat midds, minerals, vitamins, monensin sodium (48.8 mg/kg of feed) and tylosin phosphate (9.5 mg/kg of feed; Rumensin and Tylan, respectively, Elanco Animal Health, Greenfield, IN).

Group 1 diet samples were collected on the Wednesday of each week from all pens of steers housed in the north and south barns and composited by each RH dose treatment.

For Group 2, diet samples were collected on Wednesday of each week from all pens of steers housed in the north and south barns. For Group 2, diet samples were composited separately for each block and RH dose treatment. Diet samples were composited for each block by RH dose and analyzed at a commercial laboratory (Servi-Tech, Dodge City, KS). Means and SD for diet composition from all diet samples collected are reported in Table 1.

Samples were dried in a forced-air oven for approximately 72 h at 60°C to determine DM. Dry matter intake for each pen was calculated by dividing total kg of feed delivered by total head days for each pen, and weekly DM were used to calculate average daily DMI. After refusals were collected from the bunk, a subsample was placed in the same forced-air over for approximately 72 h to calculate DM. Refusals were subtracted from the weekly feed on a DM basis.

Experimental Period

The RH was mixed with 0.5 kg DDGS/steer and top dressed with the morning feeding. The appropriate amount of RH for each treatment pen was weighed daily by 1 of 2 trained individuals. Ractopamine hydrochloride was weighed on a gram scale with ± 0.02 g accuracy and mixed with DDGS for 5 min in a cement mixer (Kushlan Concrete Mixer; Sugar Land, TX). The gram scale used for daily RH was validated to 75 g (± 0.02 g) on each Wednesday throughout the RH feeding period. Three cement mixers were used, with a mixer designated for CON, 300, or 400 mg RH treatments. At randomization to treatment pen, each pen was assigned a unique color for dose and a unique color for duration. Each treatment pen had an individually labeled bucket with block number and color combination for dose and duration to prevent cross-contamination while top-dressing. Immediately following each pen's morning feed delivery, the DDGS/RH mixture was top dressed by 2 or 3 trained individuals. Steers were not allowed access to the bunk until the top dress was fully mixed with the diet. The total diet fed to calves allowed for the additional 0.5 kg inclusion of DDGS by decreasing the DDGS in the ration by 0.50 kg/steer.

On d 0 of the respective treatment duration, individual and pen weights were recorded. Thereafter, pen weights were recorded every 7 d until harvest. The individual chute scale was validated within 1.8 kg on the morning before all processing weigh days and the pen scale was certified by the State of Oklahoma before steers arrived to the feedlot. Steers on the first 5 blocks had individual and pen weights measured on d 42 and then were loaded on trucks for shipment. The final 10 blocks had individual weights measured on d 40, and pen weights were recorded before loading trucks for shipping on d 42. This d 42 or d 40 individual BW was used as the final BW for all blocks. Each block was split between 2 trucks with the first 4 ½ pens on truck 1 and the last 4 ½ pens on truck 2. Pens of steers were loaded on trucks following the same order as randomization of pen to treatment to prevent treatment bias associated with trucking. Once loaded, steers traveled approximately 435 km to the abattoir (Cargill Meat Solutions; Dodge City, KS) and cattle from both trucks were unloaded into a cement-based holding pen for approximately 3 to 4 h before harvesting.

Behavior

Chute temperament was recorded on all steers during allocation to treatment pens, on d 0 of their respective duration, and at the end of the RH feeding period. When steers entered the squeeze chute, heads were caught and they were restrained while the observer recorded the chute temperament score. Steers were evaluated based on a 4 point scale: 1 = calm, no movement; 2 = restless, shifting; 3 = squirming, occasionally shaking the squeeze chute; and 4 = continuous vigorous movement and shaking of the squeeze chute (Grandin, 1995; Voisient et al., 1997; Bernhard et al., 2014). After the 15 sec chute temperament observation, steers were evaluated upon exiting the squeeze chute. Exit score was evaluated using a four-point scale: 1 = walk; 2 = trot; 3 = run; and 4 = jump (Lanier and Grandin, 2003; Vetters et al., 2013; Bernhard et al., 2014).

Mobility

Mobility was observed on days that steers were individually processed through the squeeze chute, on d 0 of the respective RH duration start date, and at the end of the RH feeding period. A video camera (Samsung HMX-F90; Samsung Town, Seoul Korea) recorded the cattle at a 90˚ angle as they individually walked down the alleyway approximately 10 m from the chute. Distance between reference points was measured and marked with tape prior to processing the steers. From the video footage, stride length was measured using a freeze frame of each steer by measuring the distance between the furthest back rear foot to the back of the forward rear foot when both hooves were in contact with the dirt surface. The freeze frames were analyzed and length was quantified using ImageJ software (http://imagej.nih.gov/ij/) to compare the distance between the 2 rear hooves to the distance between 2 known reference points. From the same videos, an individual mobility score was assigned. Mobility was scored based on a 4 point scale: 1 = normal, long, fluid strides, and weight bearing on all four feet; 2 = slightly hesitant and stiff, shuffles feet, but still moves with the herd; 3 = obviously stiff and sore-footed, reluctant to move, cannot keep up with the herd; 4 = reluctant to move, refuses to move even when encourage by a handler, steps are short and very unsteady (Lily Edwards-Callaway; JBS, Greeley, CO). Pen and feedlot conditions were muddy due to an abnormal quantity of rain fall during Group 1 making it difficult for cattle to move "normally" and for the evaluator to score the mobility of the steers. Therefore, only data from Group 2 were included in the mobility analyses.

On the morning of shipment, pen mobility was evaluated as steers were moved to the pen scale prior to loading onto trucks using the same 4 point scale described above. As steers were individually weighed, a colored spray-painted blotch (color unique for pen within block) was applied to the tail head and the base of the left ear of each steer. The unique colors were used for pen identification (treatment identification) at the harvest facility. Steers were shipped to Cargill Meat Solutions, Dodge City, KS. At the harvest facility, steers were unloaded into grooved (approximately 5 cm depth) concrete-surfaced pens and allowed to rest approximately 2 to 4 h before harvest. After rest, steers were moved from holding pens to the abattoir (approximately 76 m) by a trained handler. As steers were moved out of the holding pens, individual animal mobility was evaluated as previously described using the unique color spray paint to identify animals within treatment.

Carcass Collection

Carcass data were collected on all steers through Cargill Meat Service (Dodge City, KS). Steers were shipped at approximately 0700 h, unloaded at the harvest facility approximately at 1200 to 1300 h and stunned at approximately 1500 to 1600 h. Hot carcass weight, liver abscess scores, and condemned gastrointestinal tracts were recorded. Liver abscesses were scored as no abscesses (O), 1 to 4 small active abscesses (A) and 1 or more large, active abscesses (A^+; Brink et al., 1990). Carcasses were chilled 40 to 48 h, ribbed at the 12th rib, and evaluated for marbling, yield grade, fat thickness, and longissimus muscle (**LM**) area. Marbling scores were used to assign a quality grade to all carcasses.

The 4th block of steers was loaded and shipped on August 12, 2015. Due to notification from the abattoir of a potential RH residue from the 3rd block of steers shipped, block 4 steers were returned to the feedlot. Trucks moved approximately 30 min out of Stillwater, OK and steers were on trucks for approximately 60 to 90 min before being returned to their original treatment pens. They were fed the same amount of DM as the prior day without RH through reshipment on August 19, 2015. The experiment investigator and personnel from WSBRC reviewed all feed records, ration/supplementation calculations, and mixing protocols, and were not able to identify an error in RH delivery. As a precaution, a 48-h RH withdrawal period prior to harvest was established for all subsequent blocks of steers enrolled in the experiment. Block 4 live performance data were included in live data analyses, but carcass data were removed from carcass data analyses due to the steers being shipped at a different time.

Three or 4 steers from each pen were randomly selected for slice shear force (**SSF**) tenderness sampling. Carcasses were sent to designated rails for further sample collection. One steak, approximately 3.8 cm thick was removed from the anterior edge of the short loin, 13th rib end, from both sides of the carcass. Steak samples were tagged individually, sealed, and shipped from the Dodge City packing facility to the Cargill Innovation Center (Dodge City, KS). One sample was aged for 14 d and the other for 21 d. After aging, both samples were frozen. Subsequently, all samples were cooked and tested on the same day to avoid day-to-day variation. Due to unforeseen timing errors within the packing facility, only 11 steak samples were collected for Block 1; therefore, Block 1 was excluded from analyses. Excluding Blocks 1 and 4, 432 carcasses were randomly selected to be sampled prior to shipping. Based on data received from the packing facility, 417 carcasses were received for SSF tenderness analyses.

Samples were thawed for approximately 24 to 36 h, cut to 2.5 cm, and weighed for a raw weight before cooking. Before cooking, internal temperature of steaks was between 35 to 37ºC. Samples were cooked in a Lincoln Impingement Oven (Fort Wayne, IN) at 71ºC for 14 min and 30 sec to ensure the 71ºC endpoint was reached. Immediately after cooking, samples were weighed for a cooked weight, and percentage shrink was calculated by subtracting raw weight from cooked weight. Internal cook temperature was measured by a Calibrated Thermometer (Digi-Sense, Vernon Hills, IL). After cook testing, a slice of each sample was removed from the lateral end that was 1.0 cm thick, 5.1 cm long, and parallel to the muscle fibers. Samples were analyzed and tested for SSF using a Texture Analyzer TAXT2i (Brewster, NY). According to the American Society for Testing and Materials (**ASTM**, 2011) classifications, qualifying meat cuts with SSF values that are $\geq$ 20.0 kg are considered not tender, or tough; SSF values between 15.4 to 19.9 are considered tender; and SSF values $\leq$ 15.3 kg are considered as very tender.

Statistical Analysis

Data were tested for normality using PROC UNIVARIATE of SAS (SAS 9.4, SAS Inst. Inc., Cary, NC). All steer performance and carcass characteristic data were analyzed with the MIXED procedure of SAS with pen serving as the experimental unit. Weight block was included as a random effect, and the model statement included dose, duration, and the dose × duration interaction. The USDA Quality Grade, USDA Yield Grade, liver abscess scores, behavior, and mobility data were analyzed using the PROC GLIMMIX procedure of SAS with pen as the experimental unit. Block was used as a random effect, and the model statement included dose, duration, and the dose × duration interaction. For pen mobility data, week and its interactions with dose and duration were also included in the model. When there were no interactions, orthogonal contrasts were used to test for significant linear and quadratic for RH duration. Orthogonal contrasts were also used for dose to test for significance for CON vs RH and 300 mg vs 400 mg RH comparisons.

Weekly pen weights were used to construct a growth curve for the 42-d RH feeding period based on the gain of RH steers over CON. Weekly weight gain was calculated by subtracting CON BW from BW of steers fed 300 and 400 mg·steer^{-1}·d^{-1} of RH. Break point analysis were analyzed as a non-linear model using the NLMIXED procedure in SAS based on methods outlined in Robbins et al. (2006). Weekly BW gains were averaged by week (7, 14, 21, 28, 35, and 42 d), dose, and block prior to analysis. Block was used as a random effect within the model. The model statement, gain ~ Normal [L + U *(zl) *(zl)] where L is the negative ordinate of the line, and U is slope of the line based on the quadratic equation of the line, and R is the number of d within the period. The model fits a quadratic function at values of $x < R$ and a straight line at values of $x > R$.

Least squares means were considered significantly different when $P < 0.05$ and a trend was declared when $0.05 \geq P \leq 0.10$. When the F-test was $P < 0.10$ and no dose × duration interaction was observed, contrasts were used to test for linear and quadratic effect of duration and the simple effects of CON vs RH and 300 mg vs. 400 mg RH.

RESULTS

During the RH feeding period, 8 steers died and another 8 steers were removed from the experiment due to health related issues. Five steers from Group 1 died (1 bloat, 1 injury, and 3 respiratory disease), and 7 steers were removed due to lameness. Three steers from Group 2 died (2 bloats and 1 injury), and 1 steer was removed due to lameness. Eight-hundred and thirty-nine steers completed the experiment.

Performance

There were no dose × duration interactions ($P \geq 0.29$) for performance response variables measured in this experiment. Therefore, main effects least squares means are shown (Table 2). Dose of RH did not have an effect on d 0 BW ($P \geq 0.36$), but by experimental design due to RH start d increasing by 7 d for increasing duration, there was a linear decrease ($P < 0.001$) in d 0 BW with increasing duration of feeding. Final BW tended (linear effect, $P = 0.07$) to increase with increasing RH dose, but was not affected ($P \geq 0.87$) by duration. There were linear dose ($P = 0.003$) and duration ($P < 0.001$) effects on live BW gain during the RH feeding period. Steers gained 6.3 and 7.2 kg more when fed 300 or 400 mg·steer^{-1}·day^{-1} of RH, respectively. As a result of differences in starting weight (by experimental design), steers on the 35-d duration gained an average of 7.3 kg more than the 28-d duration steers, and steers on the 42-d duration gained an average of 13.6 kg more than steers on the 28-d duration.

Feeding 300 and 400 mg·hd^{-1}·d^{-1} RH, respectively, increased (linear effect, $P = 0.002$) ADG by 0.20 and 0.22 kg/d, increased (linear effect, $P = 0.001$) G:F by 20.8 and 21.7%, but did affect ($P \geq 0.73$) DMI (Table 2). Duration of RH feeding did not affect ADG or G:F ($P \geq 0.32$), but DMI was decreased (linear effect, $P = 0.05$) with increasing duration. Similar to live performance, increasing RH dose linearly increased carcass-adjusted final BW ($P = 0.04$), kg of BW gain ($P = 0.002$), daily gains ($P = 0.001$), and G:F ($P = 0.004$). Duration of RH feeding did not affect carcass-adjusted ADG or G:F ($P \geq$

0.29), but carcass adjusted BW gain increased (linear effect, $P < 0.001$) as duration of feeding increased, which is a result of experiment design.

Break Point Analysis

Based on the live weight gain over CON of RH treated cattle, the prediction analysis (Table 3) predicted the minimum number of days to feed RH was 27 and 29 for the 300 and 400 mg·hd^{-1}·d^{-1} RH doses, respectively (Table 3).

Carcass Characteristics

There were no dose × duration interactions ($P \geq 0.11$) for carcass characteristics. Hot carcass weight increased linearly ($P = 0.02$) with increasing dose of RH, but was not impacted by duration of feeding ($P = 0.57$; Table 4). Dressing percent ($P \geq 0.31$) and 12th-rib fat thickness ($P \geq 0.17$) were not affected by dose or duration of RH feeding. Longissimus muscle area increased (linear effect, $P = 0.001$) as RH dose increased, but there was not an effect of duration ($P = 0.26$) on LM area. The ratio of LM area to HCW was not affected by duration ($P \geq 0.34$), but increased ($P = 0.001$) as dose of RH increased. Marbling score decreased (linear effect, $P = 0.03$) as RH dose increased. In addition, marbling score was greater (quadratic effect; $P = 0.04$) for the 35-d duration steers than the 28- or 42-d duration steers. There were no effects of RH dose ($P \geq 0.16$) or duration of feeding ($P \geq 0.19$) on USDA Quality Grades. Calculated yield grade decreased linearly ($P = 0.003$) as dose of RH increased. In addition, percentage of steers in the USDA Yield Grade 2 category increased linearly ($P = 0.008$), and percentage of steers in the USDA Yield Grade 4 category tended (linear effect, $P = 0.08$) to decrease as dose of RH increased.

Duration of RH feeding did not affect ($P \geq 0.28$) USDA Yield Grade. Steers fed for the 35-d duration tended (quadratic effect, $P = 0.07$) to have a lower percentage of A liver abscesses than steers fed for 28 or 42 d. Dose of RH did not affect the percentage of liver abscesses ($P \geq 0.19$).

Calculated carcass gain and performance data are shown in Table 5. For calculated carcass performance, d 0 HCW was predicted as d 0 BW × 0.5975. Carcass gain increased (linear effect, $P \leq 0.001$) as dose of RH and duration of feeding increased. In addition, carcass ADG ($P = 0.001$) and carcass G:F ($P = 0.002$) increased as dose of RH increased. As result of experimental design, calculated d 0 HCW (linear effect, $P < 0.001$) and carcass ADG (linear tendency, $P = 0.07$) decreased as duration of feeding increased. Carcass G:F was not affected ($P \geq 0.30$) by duration of feeding.

Tenderness-Slice Shear Force

At 14-d aging, there was a dose × duration interaction ($P = 0.02$) for the percentage of steaks with SSF values ≥ 20.0 kg (data not shown). The 400 mg RH dose had the highest percentage of steaks with SSF values equal to or above 20.0 kg. Steers fed 300 $mg \cdot steer^{-1} \cdot day^{-1}$ of RH had an intermediate percentage of steaks with SSF equal to or above 20.0 kg for the 28 and 42 d durations, but had the lowest percentage of steaks with SSF equal to or above 20.0 kg for the 35 d duration. In addition, there was a dose × duration interaction ($P = 0.05$) for average SSF at 14-d aging (data not shown). Control steers had lower SSF values for all durations. Steers fed 400 $mg \cdot steer^{-1} \cdot day^{-1}$ of RH had the highest average SSF values for the 35 d duration, whereas average SSF was higher for steers fed 300 $mg \cdot steer^{-}$

$^{1}\cdot$day^{-1} for the 28 and 42 d durations. When steers were fed increasing RH doses, there was a linear (*P* < 0.001) increase in steaks with SSF values $\geq$ 20.0 kg and a linear decrease (*P* < 0.001) in the percentage of steaks with SSF $\leq$ 15.3 kg (Figure 1a). As feeding duration increased, there was a tendency (*P* = 0.07) for a linear decrease in steaks with $\leq$ 15.3 kg SSF (Figure 1b). In addition, there was a quadratic effect (*P* = 0.01) of duration for the 14-d aged steaks with a SSF between 15.4 and 19.9 kg. Steers fed for the 35-d duration had a lower percentage of steaks with SSF between 15.4 and 19.9 kg than steers fed for 28 or 42 d.

Average SSF for 14-d aged steaks increased (linear effect, *P* < 0.001) with increasing RH dose (Figure 2a). For steaks aged for 21 d, there was an increase (linear effect, *P* = 0.002) in average SSF with increasing RH dose (Figure 2a). Duration of RH feeding did not have an effect on average SSF values for either 14- or 21-d aging (Figure 2b).

Behavior and Mobility

There was no dose × duration interaction (*P* = 0.22) for initial chute temperament score. However, there was a dose × duration interaction (*P* < 0.001) for the final chute temperament score (data not shown). Steers fed 400 mg·steer$^{-1}\cdot$d^{-1} for the 42-d duration had the highest chute temperament score of all the treatments, whereas steers fed 400 mg·steer$^{-1}\cdot$d^{-1} for the 35-d duration had the lowest chute temperament score of all the treatments. Steers were generally calm to handle, and chute temperament score averaged 1.60 on d 0 and 1.61 for the final across all treatments (Table 7). There were no dose ×

duration interactions ($P \geq 0.26$) for chute exit score. Chute exit scores decreased with increasing RH dose at both d 0 and final d (linear effect, $P < 0.001$ and $P = 0.02$, respectively). At the start of RH feeding, there was a quadratic association ($P < 0.001$) between chute exit score and increasing RH duration. However, final chute exit score was not affected ($P \geq 0.14$) by RH feeding duration.

Final stride length was increased (linear effect, $P < 0.001$) with increasing RH dose and responded quadratically ($P = 0.02$) with duration of feeding. Day 0 mobility score and harvest mobility were not affected by RH ($P \geq 0.45$). Mobility score prior to shipping steers was greater (quadratic effect, $P = 0.04$) for the 35-d duration compared with the 28 and 42-d duration steers. Dose did not affect pen mobility scores throughout the RH feeding period ($P \geq 0.11$; Figure 2). For all steers, average mobility scores for all treatments was 1.17, indicating that steers moved normal regardless of RH dose or treatment.

DISCUSSION

During May 2015, the feedlot received 12.5 cm more rainfall than the previous 10-year average for that month. Due to deteriorating pen conditions, steers from Group 1, prior to their RH treatment period, were moved to larger holding pens while attempting to improve pen conditions. Steers were housed in larger holding pens by RH dose within block (21 steers/pen) so that 3 experimental pens (regardless of duration) were in holding pen for blocks 4 through 7. A minimum of 14 d prior to the start of the 42-d RH duration, steers were sorted and returned to the experimental pens where they were originally allocated (7 steers/pen). The 3 blocks initially started on RH remained in their original treatment pens for the duration of the experiment. Mader (2014) suggested that build-up of mud within a pen decreases performance, DMI, and welfare during any season. It is difficult to determine what impact, if any, the increased mud had on performance and carcass characteristics of steers in the present experiment.

In spite of the muddy conditions, animal performance data from the present experiment are consistent with results from previous experiments (Bass et al., 2009; Vogel et al., 2009; Brown et al., 2014) when RH was fed to Holstein steers during the final 28 to 38 d of the feeding period. Previous studies have reported greater BW gain (4.3 to 8.0 kg), increased ADG (0.05 to 0.28 kg/d), and an improvement in G:F (14.2 to 16.6%) in calf-fed or yearling Holstein steers fed 200 to 300 mg·steer^{-1}·d^{-1} of RH compared with steers not fed RH (Bass et al, 2009; Vogel et al., 2009; Brown et al., 2014). In the present experiment, BW was improved by 6.3 and 7.2 kg, ADG by 0.20 and 0.22 kg/d, and G:F was increased 20.8 and 21.7%, when steers were fed 300 and 400 mg·steer^{-1}·d^{-1} of RH, respectively. The magnitude of response to RH on DMI in Holstein steers has been inconsistent. Vogel et al. (2009) reported a decrease in DMI in calf-fed Holsteins as dose of RH fed increased from 200 to 300 mg·steer^{-1}·d^{-1}. In the same experiment, DMI was increased in yearling Holstein steers fed 200 mg·steer^{-1}·d^{-1} vs. the control. Similar to the present experiment, Brown et al. (2014) reported that feeding RH did not affect DMI in calf-fed Holstein steers. Factors contributing to variation in DMI across experiments are difficult to determine, but could include frequency of weighing, weather, adaptation to RH, and DM and components of the diet, among others.

Limited data are available comparing doses of RH in diets fed to Holstein steers. Vogel et al. (2009) fed calf-fed Holstein steers 200 vs. 300 mg·steer^{-1}·d^{-1} of RH. The authors reported that increasing RH dose from 200 to 300 mg·steer^{-1}·d^{-1} decreased DMI (0.41 kg/d), but did not affect ADG or G:F. A recent experiment in beef steers showed greater final live BW, ADG, and G:F when RH was fed at 300 and 400 mg·steer^{-1}·d^{-1} vs. no RH, but there were no differences in performance with increasing dose of RH from 300 to 400 mg·steer^{-1}·d^{-1} (Bittner et al., 2017). In beef heifers, Quinn et al. (2008) reported an increase in carcass adjusted gain and G:F when heifers were fed RH for 28 d compared with a control. Increasing dose from 200 to 300 mg·heifer^{-1}·d^{-1} decreased DMI, but did not affect feedlot performance (Quinn et al., 2008). In the present experiment, increasing dose of RH resulted in linear increases in live and carcass adjusted BW gain, ADG and G:F. In addition, carcass weight gain, ADG, and G:F demonstrated a linear response when increasing dosage of RH. There was a 0.9 and 1.9 kg improvement in live and carcass adjusted gain when 400 vs. 300 mg·steer^{-1}·d^{-1} of RH was fed, respectively. Considering the linear increase in gain and efficiency, current market and other economic parameters should be evaluated to determine the most profitable dose.

The present experiment is the first to evaluate 0, 300 or 400 mg·steer^{-1}·d^{-1} of RH fed for durations of 28, 35, or 42 d in Holstein steers. In beef steers, Abney et al. (2007) evaluated the effects of RH dose (0, 100 or 200 mg RH/steer daily) and duration (28, 35 or

42 d prior to harvest) on finishing performance and carcass characteristics. Similar to the present experiment, no dose × duration interactions observed. As RH dose increased, live weight gain, ADG, and G:F increased linearly. As duration of feeding RH increased, final BW, ADG, and G:F increased or tended to increase quadratically. These authors reported increases of 7.7 and 3.6 kg in final BW when steers were fed RH for 35 and 42 d, respectively, compared with feeding ractopamine for 28 d. In a recent experiment by Bittner et al. (2017), final and carcass-adjusted final BW were greater when 200 mg·steer^{-1}·d^{-1} of RH was fed for 42 compared with 28 d. However, live and carcass adjusted ADG was not different and G:F was decreased when 200 mg·steer^{-1}·d^{-1} of RH was fed for 42 compared with 28 d. In a second experiment by Bittner et al. (2017), dose × duration interactions were observed for final BW and G:F. At 28 d, steers fed 400 mg·steer^{-1}·d^{-1} of RH had 6 kg greater final BW than steers fed 300 mg·steer^{-1}·d^{-1}. In contrast, when RH was fed for 42 d, steers fed 300 mg·steer^{-1}·d^{-1} of RH had a 3 kg greater final BW than steers fed the 400 mg·steer^{-1}·d^{-1} dose. In the present experiment, broken line break point analysis predicted additional gains above control would decrease in magnitude after 27 and 29 days in steers fed 300 and 400 mg·steer^{-1}·d^{-1} of RH, respectively.

Calculated carcass performance has been reported in the literature (Parr et al., 2011; Rathmann et al., 2012; Maxwell et al., 2014; 2015) for beef cattle. Estimating carcass-based performance is difficult because of the inability to measure carcass weight at the start of the feeding period, and as an result initial HCW must be estimated. For the calculation of carcass-adjusted performance, overall average dressing percentage of 59.75% was used.

Effects of treatment on carcass performance were similar to that observed for live performance in the present study. On a calculated carcass gain basis, steers fed 300 or 400 mg·steer^{-1}·d^{-1} of RH had 0.12 and 0.18 kg/d greater carcass ADG than control steers. Comparing steers fed RH to control steers, the improvement in calculated carcass gain averaged 19.2% to 21.8% on a carcass-adjusted gain, and 18.6% on a live gain basis. Due to similarities in DMI, these magnitudes of difference also hold true for calculated carcass efficiency. Streeter et al. (2012) reported that the ratio of carcass gain to live gain was 88% for steers, regardless of technology use. Although the ratio was closer to 0.70 for Holstein steers in the present experiment, the efficiency in which live weight was transferred to carcass weight did not appear to change due to feeding RH, similar to the results of Streeter et al. (2012).

Carcass characteristics reported in the present experiment are consistent with results from previous studies where RH was fed to Holstein steers. The present results concur with those of Bass et al. (2009), Vogel et al. (2009), and Brown et al. (2014). They reported, increased HCW (3.1 to 8.2 kg), LM area (1.54 to 2.77 cm^2), and decreased calculated YG (0.07 to 0.14 units) in carcasses from Holstein steers fed RH at a dosage of 200 to 300 mg·steer^{-1}·d^{-1} compared with control steers. In the present experiment, HCW was increased 2.9 and 4.4 kg and LM area increased by 1.3 and 2.7 cm^2 for steers fed 300 and 400 mg·steer^{-1}·d^{-1} of RH, respectively. In addition, the proportion of carcasses in the USDA Yield Grade 2 category increased, and the number of carcasses in the USDA Yield Grade 3 category tended to decrease when dose of RH was increased. Our results are generally consistent with the previous literature. In the experiment by Vogel et al. (2009), increasing RH from 200 to 300 mg·steer^{-1}·d^{-1} did not affect HCW or LM area in carcasses from calf-fed Holstein steers. In beef steers, HCW increased linearly when RH dose was fed at 0, 300, or 400 mg·steer^{-1}·d^{-1}; however, there were no differences in LM area or calculated yield grade related to RH dose (Bittner et al., 2017). Similarly, Quinn et al. (2008) reported no difference in HCW, LM area, or calculated yield grade when 200 vs. 300 mg·steer^{-1}·d^{-1} of RH was fed to beef heifers. Results from the present experiment suggest an increase in HCW and LM area as RH dose increases from 300 to 400 mg·steer^{-1}·d^{-1} in Holstein steers.

The effect of dose of RH on 12th-rib fat thickness and marbling scores have been inconsistent. In calf-fed Holstein steers, 12th-rib fat thickness was similar between steers fed 0 and 200 mg·steer^{-1}·d^{-1} RH, but was lower when 300 mg·steer^{-1}·d^{-1} was fed (Vogel et al., 2009). Fat thickness and marbling scores were not affected by feeding RH in the studies by Bass et al. (2009) or Brown et al. (2014). Similarly, no effect of RH dose on 12th-rib fat thickness or marbling scores was observed in beef steers (Abney et al., 2007; Bittner et al., 2017). In the present experiment, marbling score decreased linearly as RH dose increased; however, the distribution of USDA Quality Grades was not affected by RH dose.

Duration of RH feeding had no effect on HCW, LM area, marbling score, 12th-rib fat thickness, or the distribution of USDA Yield Grades in the present experiment. Abney et al. (2007) reported HCW being 6 and 3 kg heavier for steers fed for 35 and 42 d, respectively, compared with steers fed for 28 d. Feeding 300 mg·steer^{-1}·d^{-1} of RH for 28 or 42 d increased HCW by 5.1 and 8.9 kg, respectively, compared with steers fed 0 mg RH (Bittner et al., 2017). In addition, Bittner et al. (2017) reported that feeding 400 mg·steer^{-1}·d^{-1} of RH for 28 or 42 d resulted in increases of 7.6 and 8.9 kg, respectively, in HCW compared with steers fed 0 mg RH (Bittner et al., 2017). In the present experiment, HCW over controls was linearly affected by dose, but was similar when RH was fed for 28, 35 or 42 d.

Martin et al. (2014) reported that steaks from calf-fed Holstein steers fed 300 mg·steer^{-1}·d^{-1} of RH had greater SSF values than steaks from steers not fed RH. In addition, steaks from steers fed RH had greater SSF values regardless of postmortem aging length. Similar to the present experiment, Howard et al. (2014) evaluated the effects of feeding 0, 300 or 400 mg·steer^{-1}·d^{-1} of RH to calf-fed Holstein steers the final 31 d of finishing. Steers fed RH produced steaks with SSF values greater than controls; however, no difference was detected between the two levels of RH at either 14- or 21-d aging. In the present experiment, the probability of steaks aged 14 d meeting the SSF requirements to be certified tender (SSF < 20 kg) was 0.85 and 0.83 in steers fed 300 or 400 mg·steer^{-1}·d^{-1} of RH, respectively, compared to controls. After 21-d aging, the probability of steaks meeting the SSF requirements to be certified tender was 0.97 and 0.92 in steers fed 300 or 400 mg·steer^{-1}·d^{-1} of RH, respectively, compared to controls. Increasing dose of RH, regardless of aging, increased average SSF values, but 88.6 and 98.0% of steaks had a SSF < 20.0 kg after 14- and 21-d aging, respectively. In addition, SSF value for steaks aged for 21 vs. 14 d was numerically lower, especially for steaks from steers fed 400 mg·steer^{-1}·d^{-1}

of RH. Duration of feeding did not affect average SSF values in the present experiment. Results from the present experiment suggest the percentage of steaks with $\geq$ 20.0 kg of SSF will increase with increasing dose of RH. However, some of the negative effect of increasing RH dose can be mitigated if steaks are aged for 21 d postmortem.

With the increased awareness of animal welfare, it is prudent to observe if βAA affect animal well-being. Lyles and Calvo-Lorenzo (2014) indicated there is little evidence of welfare implications of feeding βAA. Although a dose × duration interaction was observed, the present experiment did not detect a difference in chute temperament score related to dose of RH. Results from the present experiment are similar to Baszczak et al. (2006) who reported no changes in chute temperament score between steers supplemented with or without RH. In the present experiment, there were significant RH dose and duration effects on chute exit score on d 0 at the start of RH feeding. Therefore, d 0 chute exit score was included in the model as a covariate for final chute exit score. Chute exit score at the end of the RH feeding period decreased as RH dose increased in the present experiment. In the experiment by Baszczak et al. (2006), chute exit score was unaltered by βAA supplementation. Using the same chute temperament scoring as the present experiment, Hagenmaier et al. (2017) observed that prior to transport to the harvest facility, a higher percentage of beef steers not treated with RH had chute temperament scores and chute exit scores > 1 when compared to RH treated steers. Results from the present experiment suggest that dose and duration of RH feeding have little to no effects on chute temperament and exit scores in Holstein steers.

There is limited data on stride length in feedlot cattle receiving various growth promoting technologies, although, stride length, gait, and mobility are utilized within the dairy industry to identify lameness issues. In Holstein dairy cows, longer stride lengths (Flowers and Weary, 2006) and decreased lameness issues (Telezhengo et al., 2017) were reported in cows moved on soil or rubber based areas compared to concrete surfaces. In the present experiment, the alleyway where stride length was measured was dirt surfaced along with the majority of the experimental pen. It is unclear why increasing RH dose (linear effect) and increasing duration (quadratic effect) increased stride length in Holstein steers. Although data are limited in beef steers, Bernhard (2014) concluded that feeding zilpaterol hydrochloride did not affect step length. Considering frame and structural difference in beef and Holstein cattle types, step lengths of approximately 43 cm of Holstein steers compare to the 58 cm stride lengths (one stride is equal to two steps) of beef steers reported by Bernhard (2014).

In the present experiment, mobility scores were observed as individual animals exited the squeeze chute. Dose of RH did not affect individual mobility scores captured at the end of the feeding period, although there was a quadratic increase in mobility score associated with duration of RH feeding. These results are supported by Boyd et al. (2015) who used a similar scoring system and concluded that mobility was not affected in cattle fed zilpaterol hydrochloride when cattle were scored in a group. Using the same mobility scoring in a group scoring system, Hagenmaier et al. (2017) reported no difference in percentage of cattle with a mobility score > 1 when comparing RH treated and control cattle. In the present experiment, steers were handled in a low-stress manner at all times. In the experiment by Hagenmaier et al. (2017), beef steers were processed with either high-stress or low-stress handling methods, which may have affected the behavior and mobility results reported in their experiment. In another study, cull Holstein cows were fed an 86% concentrate diet the final 90 d prior to harvest (Allen et al., 2009). When half of those cows were supplemented with 312 mg·cow^{-1}·d^{-1} of RH the final 32 d on feed, RH treatment had no effect on locomotion score. Similarly, supplementation of zilpaterol hydrochloride to market dairy cows had no effect on locomotion score (Lowe et al., 2012). In the present experiment, steers were scored as each group was moved from their holding pens to the processing area, and were individually assigned a mobility score by the same technician as they were moved into the abattoir. Treatment had no effect on pen mobility score or mobility at harvest. Boyd et al. (2015) reported that although no impact was observed for feeding zilpaterol hydrochloride on cattle mobility scores, mobility scores decreased for all cattle at harvest.

The addition of RH the last 28 to 42 days on feed in Holstein steer diets increased BW gain, ADG, G:F, HCW, and LM area. Results suggest feeding up to 400 mg·steer^{-1}·d^{-1} will improve Holstein steer performance and carcass characteristics when RH is fed for 28, 35, or 42 days. It should be noted the percentage of steaks classified as not tender or tough was 10 percentage points greater for steers fed 400 vs. 300 mg·steer^{-1}·d^{-1} of RH after aging for 14 d, but decreased to only 1.0 percentage point difference after 21 d of aging. We conclude feeding RH has little to minimal effects on animal behavior or mobility. Increasing dose of RH up to 400 mg·steer^{-1}·d^{-1} fed for the last 28 to 42 d of the feeding period can improve live weight gain, efficiency, and carcass gain and leanness.

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Table 3.1: Finishing diet ingredients, supplement, and composition fed to Holstein steers with 0, 300, or 400 mg·steer-1·d-1 of ractopamine hydrochloride

Item		Receiving[1]	Finishing
Ingredient, %	Steam flaked corn[2]	58.49	61.60
	Dried distillers grain solubles	16.49	16.47
	Alfalfa hay	5.77	4.27
	Prairie hay	10.20	8.65
	Feed Fat	3.45	3.45
	Water	0.10	0.11
	Dry supplement[3]	5.50	5.50
Composition			
	NE_m , Mcal/kg		0.95 ± 0.04
	NE_g, Mcal/kg		0.65 ± 0.03
	CP, %		13.35 ± 0.66
	ADF %		11.53 ± 1.23
	NDF %		21.73 ± 2.29
	Fat, %		7.22 ± 0.45
	Calcium, %		0.67 ± 0.12
	Phosphorus, %		0.35 ± 0.03
	Magnesium, %		0.18 ± 0.01
	Potassium, %		0.66 ± 0.04

[1]Recieving diet was fed when steers arrived at feedlot and for a consecutive 7 d during transition onto the finishing diet. Finishing diet was fed for an average of 150 d.

[2]Starch availability, 50%; total starch, 74.35%; flake weight, 11 kg/bushel.

[3]Supplement ingredients included: ground corn, 36.10%; limestone, 28.50%; wheat midds, 19.75%; urea, 6.50%, magnesium oxide, 0.96%; zinc sulfate, 0.58%; salt, 0.36%; copper sulfate, 0.11%; manganese oxide, 0.11%; selenium pre-mix, 0.05%; vitamin A (30,000 IU/g), 0.29%; vitamin E (500 IU/g), 0.08%; monensin, 0.45%; tylosin, 0.23%. Monensin and tylosin (Rumensin and Tylan, respectively, Elanco Animal Health) were fed at a calculated rate of 48.8 mg/kg and 9.5 mg/kg daily, respectively. Ractopamine hydrochloride was fed at a rate of 0, 300, or 400 mg·steer^{-1}·d^{-1} for 28, 35, or 42 d at the end of the feeding period.

Table 3.2: Effects of feeding ractopamine hydrochloride at a dose of 0, 300, and 400 mg·steer^{-1}·d^{-1} for a duration of 28, 35, and 42 d on BW[1] and performance of Holstein steers

	Dose				*P*-value		Duration				*P*-value	
Item	0	300	400	SEM	Linear	Quadratic	28	35	42	SEM	Linear	Quadratic
Pens	15	15	15				15	15	15			
Total steers	276	280	283				280	281	278			
BW, kg												
Arrival[2]	423	420	422	8	0.36	0.26	420	423	422	8	0.56	0.32
d 0	599	598	596	5	0.35	0.69	605	598	591	5	<0.001	0.90
Final[3]	635	641	640	6	0.07	0.43	639	639	639	6	0.87	0.97
BW gain, kg[4]	36.4	42.7	43.6	3.8	0.003	0.51	34.1	41.4	47.7	3.8	<0.001	0.97
ADG, kg/d[5]	1.03	1.23	1.25	0.11	0.002	0.58	1.21	1.17	1.14	0.11	0.32	0.90
DMI, kg/d[6]	9.50	9.52	9.58	0.23	0.73	0.82	9.72	9.56	9.36	0.23	0.05	0.85
G:F[7]	0.106	0.128	0.129	0.010	0.002	0.64	0.123	0.121	0.121	0.010	0.75	0.82
Carcass-adjusted performance[8]												
Final BW, kg	635	640	641	7	0.04	0.89	639	639	638	7	0.68	0.83
BW gain, kg	35.6	42.4	44.3	3.7	0.002	0.91	33.9	41.3	47.1	3.7	<0.001	0.75
ADG, kg	1.02	1.21	1.28	0.11	0.001	0.99	1.21	1.18	1.12	0.11	0.29	0.84
G:F	0.106	0.127	0.132	0.012	0.004	0.86	0.123	0.123	0.120	0.012	0.73	0.96

[1]A calculated shrink of 4% was applied to all BW measurements.
[2]Arrival BW taken approximately 36 h after arrival to the feedlot.
[3]End of ractopamine feeding period after a duration of 28, 35, or 42 d.
[4]BW gain calculated as (final BW - d 0 BW).
[5]ADG from start to end of ractopamine hydrochloride feeding period.
[6]DMI from start to end of ractopamine hydrochloride feeding period.
[7]G:F calculated as (ADG/DMI).
[8]Calculated from live weight adjusted for a 60.41% common dressing percentage. Data included all 15 Blocks.

Table 3.3: Predicted[4] number of days to fed 300 or 400 mg·hd^{-1}·d^{-1} ractopamine hydrochloride (RH) to Holstein steers based on weekly gain over control[2]

RH Dose	Predicted Days ± SEM[1]
300 mg/hd	27.0 ± 0.76
400 mg/hd	29.0 ± 0.76

[1]Predicted number of d to fed RH based on weekly weight gain to predict when gains will approach zero. A broken line break point analysis model was used: Gain = L + U + (R – x) * (R – x). L = negative ordinate U = slope of quadratic line R = maximum # of days in period; R – x value is zero at values of x > R. Block was used as a random effect within the model. Methods adapted from Robbins et al. (2006).

[2]Steers did not receive ractopamine hydrochloride throughout the period. Ractopamine hydrochloride fed for 28, 35, or 42 d were all included in the analysis. Pen weights were obtained every 7 d while RH was fed. Gain over control calculated by subtracting the gain of control from the 300 and 400 mg RH weekly gains.

Table 3.4: Effects of feeding ractopamine hydrochloride at a dose of 0, 300, and 400 mg·steer^{-1}·d^{-1} for a duration of 28, 35, and 42 d on carcass characteristics in Holstein steers.

	Dose				*P*-value		Duration				*P*-value	
Item	0	300	400	SEM	Linear	Quadratic	28	35	42	SEM	Linear	Quadratic
Pens	14	14	14				14	14	14			
Total Steers	256	260	263				260	261	258			
HCW, kg	383	386	387	4	0.02	0.81	385	386	384	4	0.57	0.57
Dressing percent, %	60.2	60.3	60.4	0.5	0.31	0.64	60.3	60.3	60.3	0.5	0.91	0.63
Marbling scores	484	471	466	8	0.03	0.65	470	483	468	8	0.70	0.04
LM area, cm^2	78.0	79.3	80.7	0.7	0.001	0.53	80.0	78.7	79.4	0.7	0.26	0.44
LM/HCW, cm^2/kg	0.204	0.207	0.209	0.002	0.001	0.73	0.208	0.205	0.206	0.002	0.46	0.34
12th rib fat thickness, cm	0.88	0.86	0.84	0.02	0.17	0.98	0.85	0.87	0.86	0.02	0.58	0.43
Calculated yield grade	3.21	3.12	3.07	0.06	0.003	0.72	3.09	3.17	3.14	0.06	0.34	0.37
USDA Quality Grade[1]												
Prime, %	0.8	0.0	0.4	0.1	0.28	0.30	0.0	0.8	0.4	0.1	0.45	0.19
Choice, %												
High	12.5	8.8	9.0	2.3	0.22	0.72	9.8	12.5	8.0	2.3	0.58	0.19
Low	70.7	66.9	69.3	3.0	0.59	0.47	69.3	67.4	70.2	3.0	0.84	0.53
Select, %	16.0	24.3	21.3	3.0	0.16	0.18	21.0	19.3	21.5	3.0	0.88	0.54
USDA Yield Grade												
YG 1, %	3.5	2.9	3.4	1.4	0.86	0.74	3.9	3.3	2.5	1.4	0.35	0.98
YG 2, %	32.3	40.9	42.6	4.1	0.008	0.82	42.0	36.1	37.6	4.1	0.28	0.30
YG 3, %	56.8	52.5	50.2	3.6	0.11	0.86	50.7	54.3	54.5	3.6	0.36	0.64
YG 4, %	7.5	3.8	4.0	1.9	0.08	0.61	3.4	6.4	5.5	1.9	0.36	0.32
Liver abscess[2]												
A, %	24.4	17.8	21.1	2.8	0.19	0.21	22.8	17.2	23.3	2.8	0.89	0.07
A$^+$, %	36.4	36.7	39.2	4.0	0.58	0.63	37.1	37.8	37.4	4.0	0.95	0.89
O, %	37.8	43.3	37.9	4.4	0.68	0.19	37.6	43.5	37.8	4.4	0.97	0.14
Other, %	1.7	2.3	2.1	1.1	0.69	0.79	2.7	1.5	1.8	1.1	0.46	0.49

[1]Quality grade assigned based on carcass marbling scores: < 400 – select; 401 to 600 – low choice; 601 to 800 – high choice; > 801 – prime.

[2]Liver abscess scoring was adapted from Brinks et al., 1990. Livers were scored as follows: No abscesses (O), 1 to 4 small active abscesses (A), or one or more large, active abscesses (A^+).

Table 3.5: Effects of feeding ractopamine hydrochloride at a dose of 0, 300, or 400 mg·steer^{-1}·d^{-1} for a duration of 28, 35, 42 d on carcass gain in Holstein steers

	Dose				*P*-value		Duration				*P*-value	
Item	0	300	400	SEM	Linear	Quadratic	28	35	42	SEM	Linear	Quadratic
Actual HCW, kg	382.7	385.6	387.1	3.98	0.02	0.81	385.4	385.7	384.3	3.98	0.57	0.57
Initial HCW, kg[1]	356.9	356.2	355.6	3.25	0.40	0.71	360.9	356.0	351.9	3.25	<0.001	0.77
Carcass gain, kg[2]	25.5	29.6	31.3	2.57	0.001	0.34	24.3	29.6	32.4	2.57	<0.001	0.41
Gain over 0, kg	-	4.1	5.8				-	5.3	8.1			
Carcass ADG, kg/d[3]	0.73	0.85	0.91	0.07	0.001	0.31	0.87	0.85	0.77	0.07	0.07	0.56
Carcass G:F[4]	0.076	0.089	0.095	0.008	0.002	0.98	0.090	0.088	0.082	0.008	0.30	0.53

[1]Initial HCW calculated as d 0 BW × 59.75%.
[2]Carcass gain calculated as (Actual HCW – Predicted HCW)
[3]Carcass ADG calculated as (Carcass gain/Duration)
[4]Carcass G:F calculated as (Carcass ADG/DMI)

Table 3.6: Effects of feeding ractopamine hydrochloride fed at 0, 300, or 400 mg·steer^{-1}·d^{-1} for a duration of 28, 35, or 42 d on chute temperament[1], exit scores[2], individual mobility[3], and harvest mobility of Holstein steers.

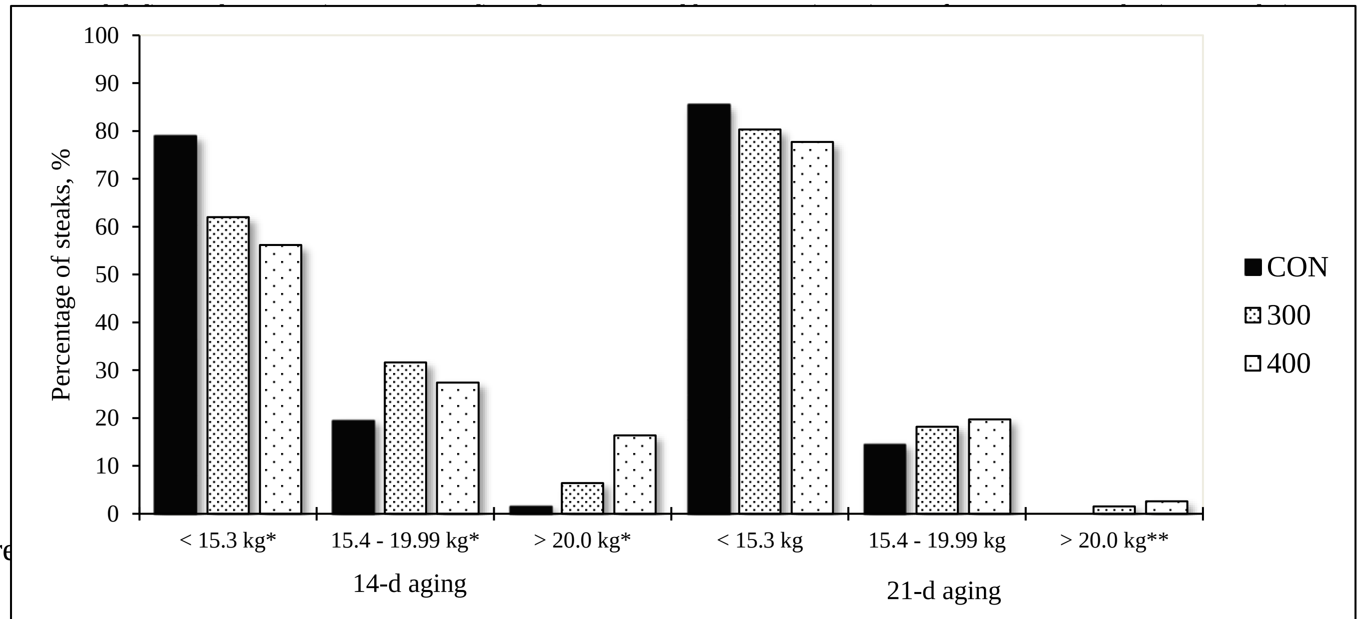
	Dose				*P*-value		Duration				*P*-value	
Item	0	300	400	SEM	Linear	Quadratic	28	35	42	SEM	Linear	Quadratic
Pens	13	13	13				13	13	13			
Steers	237	239	241				238	239	240			
Chute Temperament												
d 0[2]	1.68	1.61	1.51	0.09	0.11	0.52	1.60	1.61	1.51	0.09	0.35	0.09
Final[3]	1.65	1.57	1.62	0.25	0.55	0.45	1.64	1.54	1.66	0.25	0.88	0.10
Chute Exit												
d 0	1.79	1.58	1.50	0.12	<0.001	0.95	1.67	1.47	1.74	0.12	0.51	<0.001
Final[4]	1.39	1.26	1.21	0.20	0.02	0.55	1.25	1.25	1.35	0.20	0.14	0.45
Pens	8	8	8				8	8	8			
Steers	137	135	138				137	136	136			
Stride Length[5], cm												
d 0	40.8	41.4	41.7	0.03	0.37	0.76	43.3	40.4	40.6	0.30	0.02	0.31
Final	43.1	44.9	47.4	0.02	<0.001	0.96	43.2	47.9	44.9	0.20	0.37	0.02
Mobility[6]												
d 0	1.17	1.13	1.14	0.06	0.45	0.67	1.16	1.13	1.15	0.06	0.79	0.66
Final	1.18	1.17	1.16	0.04	0.67	0.93	1.14	1.24	1.13	0.04	0.88	0.04
Harvest Mobility[7]	1.32	1.39	1.37	0.06	0.19	0.45	1.32	1.41	1.35	0.06	0.53	0.11

[1]Steers were observed in a squeeze chute for 15 sec after their head was caught, by one blinded, trained observer. The 1 to 4 point scoring system was adapted from Grandin (1995): 1 = calm, no movement; 2 = restless shifting; 3 = head throwing, squirming and occasionally shaking the squeeze chute; 4 = violently and continually shaking the squeeze chute.
[2]Steers were observed as steers left the squeeze chute by one trained individual. The 1 to 4 point scoring system was adapted from Grandin (1995): 1 = normal walk; 2 = trot or fast walk; 3 = run or sprint; 4 = leap or jump.
[3]Steers were evaluated for individual mobility while moving approximately 30 ft from exiting the squeeze chute. The 1 to 4 point scoring system was adapted from Lily Edwards-Callaway, JBS: 1 = normal, fluid, even rhythm, and weight bearing on all four feet; 2 = slightly hesitant and stiff, shuffles feet, but still moves with the herd; 3 = obviously still and sore footed, reluctant to move, cannot keep up with the herd; 4 = extremely reluctant to move, animal refused to move when encouraged by a handler; any steps are short and very unsteady.
[4]Respective duration ractopamine hydrochloride feeding d 0.
[5]Last day of ractopamine hydrochloride feeding.
[6]Last day of ractopamine hydrochloride feeding. d 0 chute exit score was used as a covariate in the model (P = 0.01).
[7]Steers were observed for individual stride length while moving approximately 4 m from the squeeze chute by measuring the distance between the furthest back rear foot to the back of the forward rear foot when both hooves were in contact with the dirt surface.
[9]Harvest mobility scores were observed at packing plant as steers were moved into harvest facility.

Figure 3.1: Effect of ractopamine hydrochloride dose (1a) and duration (1b) on slice shear force (SSF[1]) distribution after 14- or 21-d aging

*Linear effect when $P < 0.05$. ** Quadratic effect when $P < 0.05$. Slice shear force was collected on 3 to 4 randomly selected steers from each pen (n = 417). Ractopamine hydrochloride was fed at 3 doses (o (CON), 300, or 400

Figure 3.1a



Figure

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Figure 3

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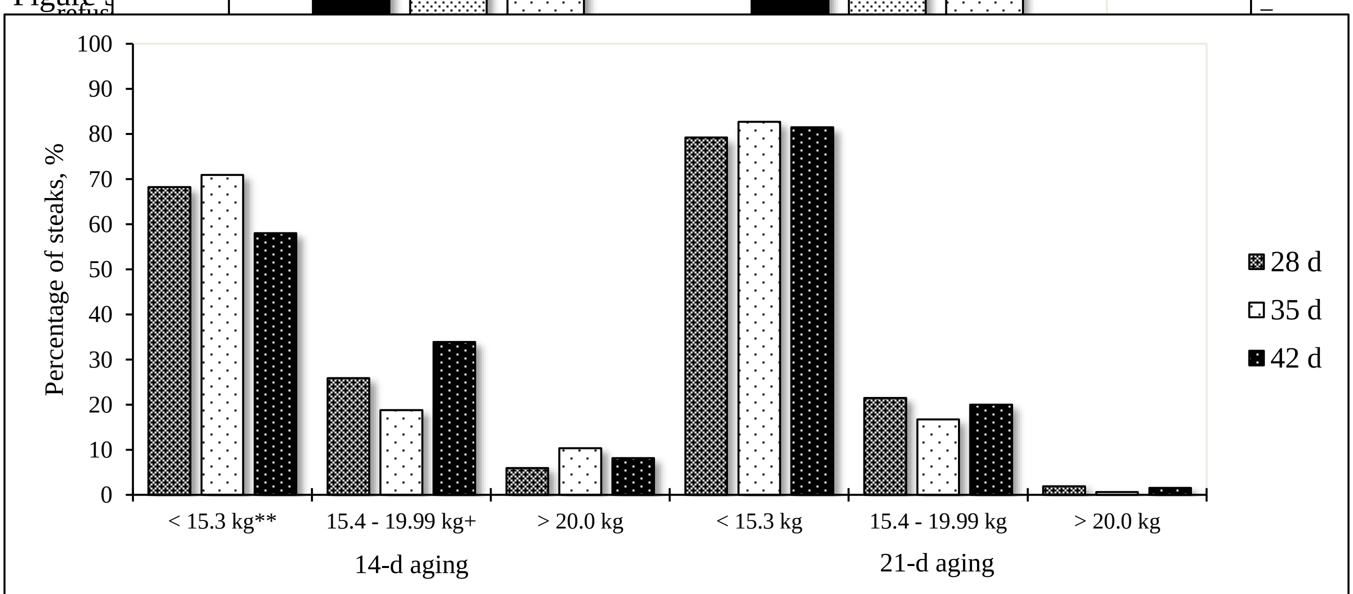

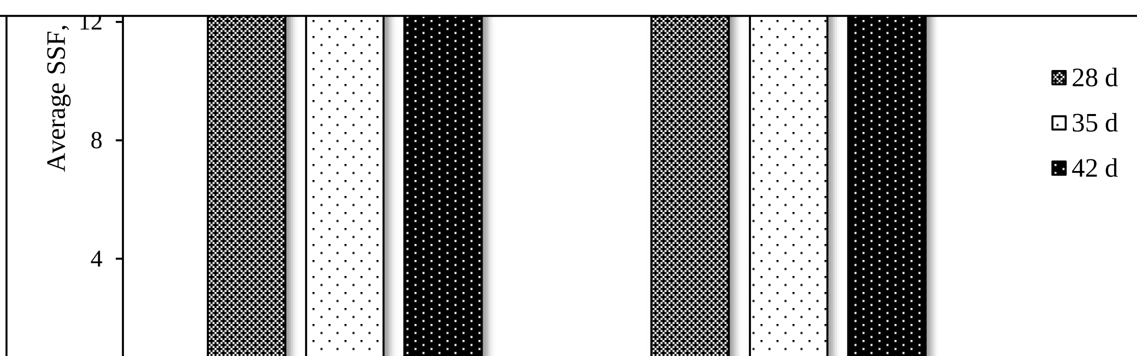

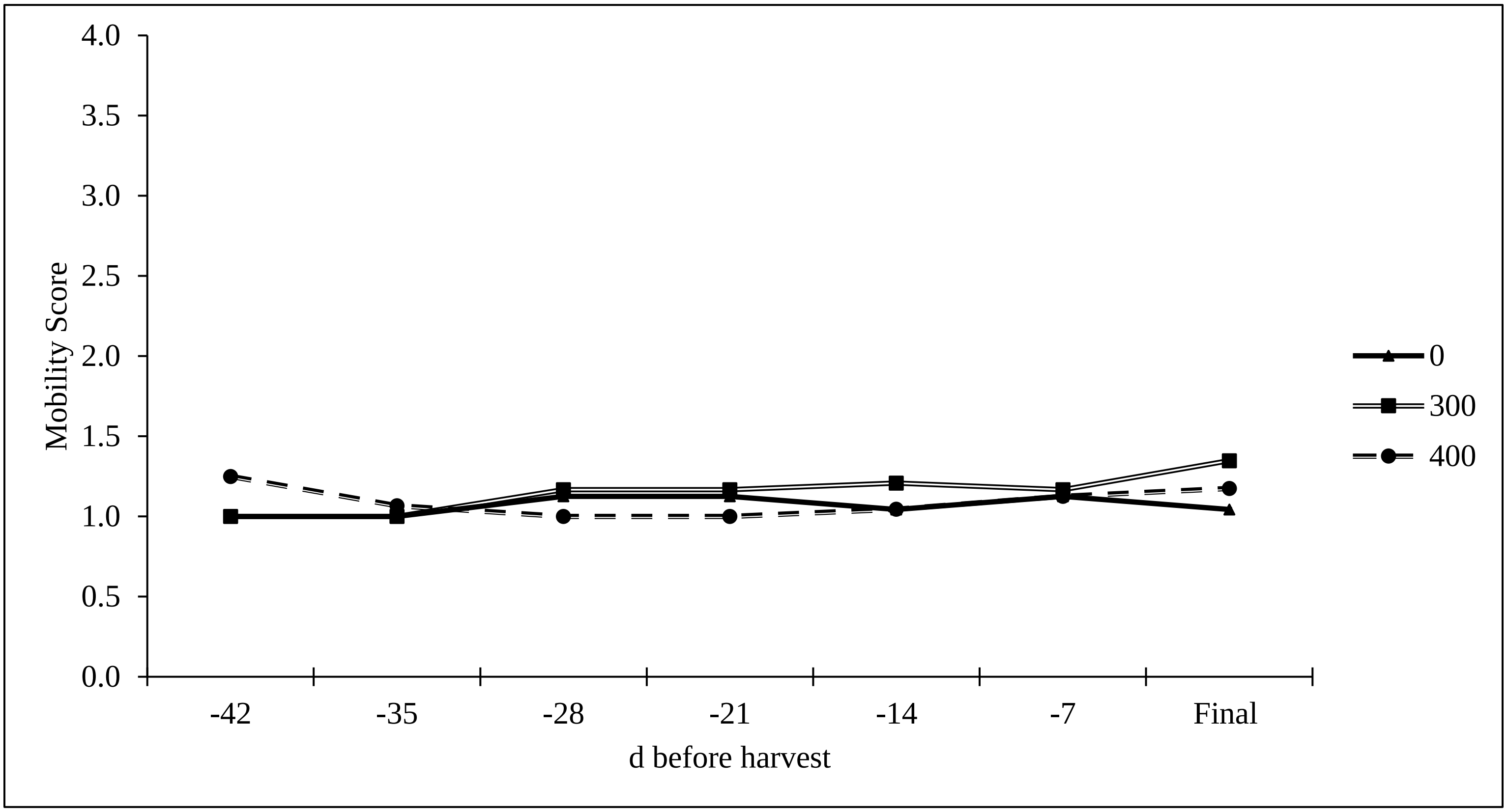
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Mobility Score
-42
-35
-28
-21
-14
-7
Final
d before harvest
0
300
400

CHAPTER IV

EFFECTS OF COMPREHENSIVE CLIMATE INDEX ON RUMEN TEMPERATURE OF BEEF CATTLE

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ABSTRACT: Many factors have potential to increase core body temperature of beef cattle, including environmental conditions, ruminal fermentation, and illness. Black-hided, feedlot steers (*n* = 143; initial BW = 392 $\pm$ 22 kg) and red-hided, replacement heifers (*n* = 25; initial BW = 450 $\pm$ 46 kg) were used in an experiment to determine the effect environmental conditions, characterized by the comprehensive climate index (**CCI**), on rumen temperature (**RuTemp**). Steers were housed in open-aired, feedlot pens in Stillwater, OK from May to August 2013. Heifers were housed in a native rangeland pasture (43 ha) in Fort Supply, OK from March to July 2015. Environmental conditions were recorded in 5-min intervals and used to calculate the CCI. Rumen temperature and CCI observations were divided into 4, 6-hr intervals (**TOD**; 0000 to 0559 h, **E-AM**; 0600 to 1159 h, **AM;**, 1200 to 1759 h, **E-PM** and 1800 to 2359 h, **PM**) and 2 seasons, spring (March 1 to May 31) and summer (June 1 to August 31). Based on hourly average CCI values, 1 of 4 stress thresholds were assigned (no stress, mild, moderate, severe, and extreme) to determine average and maximum RuTemp. Daily average RuTemp and daily average CCI were strongly related for steers (R^2 = 0.57) and heifers (R^2 = 0.73) indicating that CCI impacts RuTemp. There was a season × TOD interaction for average and maximum RuTemp for steers (P < 0.001) and heifers (P < 0.001). Steers had elevated RuTemp in the summer during E-PM and PM periods and heifers during PM in the summer. Rumen temperatures were lowest in the AM during the spring for steers (P < 0.001) and heifers (P < 0.001). There was a season x stress threshold interaction for RuTemp for steers (P < 0.001) and heifers (P < 0.001). In summer, during No Stress environmental thresholds average RuTemp was lowest for steers and heifers (P < 0.001) and were highest during Severe and Extreme environmental thresholds in the summer (*P*

< 0.001). There was a season × stress threshold interaction for lag time for steers (P < 0.001) and heifers (P < 0.001). Lag time was longest during No Stress conditions during spring (P < 0.001) and shortest in the summer during Extreme conditions for steers (P < 0.001) and heifers (P < 0.001). During heat stress conditions, use of CCI has potential to be used to predict changes in RuTemp. Predicted RuTemp will provide opportunity to identify individual animals that are experiencing thermal stress or account for environmental conditions when using RuTemp for identification of other conditions such as disease or reproductive activities.

KEYWORDS: beef cattle, comprehensive climate index, feedlot, heat stress, heifer, rumen temperature

INTRODUCTION

Daily fluctuations in core body temperature (**CBT**) are influenced by a number of variables including body composition, diet, ruminal fermentation, and environment conditions. Rumen temperature (**RuTemp**) boluses (Smartstock, LLC; Pawnee, Oklahoma) allow for continuous temperature monitoring without inducing stress or additional activity. Previously, RuTemp monitoring has been shown to be effective in identifying changes in physiological state of beef cattle including estrus, parturition, gestation, and illness (Boehmer et al., 2015; Cooper-Prado et al., 2011; Rose-Dye et al., 2011; Wright et al., 2014). Limited research is available assessing the impact of environmental conditions on RuTemp of beef cattle.

Previous research has found a positive relationship ($R^2 > 0.50$) between increasing ambient temperature and increasing CBT of lactating dairy cattle (Liang et al., 2013;

Ammer et al., 2016). Ruminants use heat transfer methods to dissipate heat. Evaporative heat loss occurs when ambient air temperatures are below CBT allowing body heat to transfer into the environment (Ammer et al., 2016; Boehmer et al., 2015). Overnight, decreased solar radiation exposure and ambient temperatures aid in reducing CBT and prevent heat carry over into the next day. Carryover is especially harmful in heat waves lasting several days because it can accumulate into dangerous levels.

The interaction between multiple environmental variables interact to create the impact on cattle. Mader et al. (2010) developed the Comprehensive Climate Index (**CCI**) which is an environmental index for livestock that incorporates multiple environmental factors. The index includes humidity, air temperature, solar radiation, wind speed, and soil surface temperature.

We know of no other publications that evaluate the impact of CCI on RuTemp of beef cattle. Therefore, the objective of this experiment is to characterize the impact of environmental conditions, as summarized in the CCI, on RuTemp of beef cattle.

MATERIALS AND METHODS

All protocols were approved by the Oklahoma State University Institutional Animal Care and Use Committee.

Cattle Management

Steers.

Black-hided, crossbred steers (*n* = 143; initial BW = 392 ± 22 kg) arrived at Willard Sparks Beef Research Center in Stillwater, OK in the spring of 2013. Steers were used in an experiment to determine the impact the CCI on RuTemp of feedlot steers. Steers in the present experiment were selected based on pen median BW (6 steers/pen) from a larger experiment (*n* = 336; initial BW = 395 $\pm$21 kg). Upon arrival, steers were weighed individually and received a unique number identification ear tag. Based on d -1 BW, steers were allocated to an experimental treatment and pen. Experimental treatments included an all-natural, conventional, and conventional with a β-adrenergic agonists (**βAA**). Natural treatment did not receive growth promoting technologies or antibiotics throughout the feeding period. Both conventional treatments were implanted with 40 mg of estradiol and 200 mg of trenbolone acetate (**TBA**; Revalor-XS; Merck Animal Health, DeSoto, KS) at arrival and were fed a pelleted dry supplement with 33 and 9 mg/kg of monensin and tylosin (Rumensin and Tylan, Elanco Animal Health, Greenfield, IN), respectively. Conventional with βAA treatment received a dry pelleted supplement with zilpaterol hydrochloride at a rate of 6.76 mg/kg (Zilmax; Elanco Animal Health) for the last 20 d on feed with a 3 d withdrawal prior to harvest. Steers were fed daily at approximately 0700 and 1300 h. Natural steers were fed first to prevent treatment cross contamination. All steers were fed a finishing diet twice daily that consisted of dry-rolled corn, switch grass hay, dried distillers grains, corn gluten feed, and a liquid and dry supplement that differed among experimental treatment. The finishing diet was formulated to meet the steers nutritional requirements based on the NRC (2000). Steers were housed in (*n* = 24) 12.2 x 30.5 m, soil surfaced, open-air feedlot pens, with 12.2 m concrete bunk lines, and a 76 L concrete fence line waterer that was 1 m x 1 m (Model J-360 F, Johnson Concrete, Hasting NE). The waterer was located on the fence line shared between 2 pens so that approximately 26 steers (0.04 m^2/steer) shared a waterer.

Additional information on cattle management and performance results can be found Maxwell et al. (2015).

Heifers.

Red Angus, replacement heifers (12 to 13 mo of age; (n = 25; initial BW 450 $\pm$ 46 kg) grazed a native rangeland pasture located in Fort Supply, OK (43 ha) throughout the spring and summer of 2015. Within the pasture, shade was not provided and water was supplied through a windmill pump, overflowing stock tank at one end of the pasture. Heifers were given limited access daily to an automated head chamber system (GreenFeed; C-Lock Inc., Rapid City, SD) that measured respired gas emissions (Gunter et al., 2017). The GreenFeed system provided a dry, pelleted, supplement used to entice heifers to put their heads into the system; mean intakes of the bait was approximately 1 $kg \cdot hd^{-1} \cdot d^{-1}$. Pellets consisted of ground corn, wheat midds, ground alfalfa hay, cane molasses, corn steep water, calcium carbonate, sodium bentonite, and grain by-products. Data from the automated system was not included in the RuTemp analysis.

Data Analysis

Data was analyzed to determine the effect of time of d (**TOD**) and season on RuTemp. Daily observations were divided into four 6 hr periods based on solar radiation exposure; early morning (**E-AM**; 0000 to 0559 h), morning (**AM**; 0600 to 1159 h), afternoon (**E-PM**; 1200 to 1759 h), and evening (**PM**; 1800 to 2359 h). Seasons were determined based on the Oklahoma Mesonet (www.Mesonet.org); 61 d period (March 1 to May 31) for spring and 91 d period (June 1 to August 31) for summer.

Rumen temperature collection.

Steers RuTemp boluses (SmartStock; LLC, Pawnee, OK) were administered in May of 2013 when steers were allocated to experimental pens. Rumen temperatures from May to August 2013 (114 d) were used for the analysis. Boluses were programmed to transmit temperatures in 3 min intervals and receivers were located on the fence line in adjacent experimental pens to maintain steers within 9 m of a receiver. Heifers RuTemp boluses were administered in March of 2015 when heifers were moved into the pasture. Rumen temperature observations from March to July 2015 (116 d) were used for the analysis. Boluses were programmed to record and transmit temperatures in 120 min intervals and receivers were located next to the water tank.

Area under the curve (**AUC**) calculations were utilized to determine the quantity of time RuTemp were elevated. The following equation were utilized to calculate AUC for all observations (Wahrmund, 2008 and Haviland, 2015):

$$\text{Equ. 1: AUC} = \frac{(\text{Current time}) - (\text{Lag time}) * (\text{Current RuTemp}) + (\text{Lag RuTemp})}{2}$$

If RuTemp were greater or equal to 39.4, 40.0, or 41.1°C, AUC was calculated. If RuTemp was less than 39.4, 40.0, or 41.1°C, AUC was assigned a zero. Area under the curve calculations were summed by h prior to the analysis. To determine the percentage of a period the animal had an elevated RuTemp, the following equation were used:

$$\text{Equ. 2: \% of Period} = \frac{(\text{Elevated Summed AUC})}{(\text{Period Total AUC})} * 100$$

Lag time and Ratio.

Lag time calculations were used to determine time lapse between daily maximum CCI and daily maximum RuTemp. To calculate lag time, CCI and RuTemp were averaged hourly and the h in which maximum CCI occurred was subtracted from the h maximum RuTemp occurred. If the maximum RuTemp occurred prior to maximum CCI, a negative lag time was calculated and the observations were removed from the analysis.

The ratio of RuTemp to CCI (**RuTemp:CCI**) and CCI to RuTemp (**CCI:RuTemp**) were calculated to determine the increment of increase CCI or RuTemp to the other measure. Rumen temperature and CCI were averaged daily for individual animals. Across all animals, daily average RuTemp and CCI were plotted to determine their relationship.

Environmental data collection.

Environmental conditions for Woodward and Stillwater, OK were collected in 5 min intervals from the Oklahoma Mesonet (www.Mesonet.org; Table 1) and CCI values were calculated based on equations from Mader et al. (2010).

Comprehensive climate index stress thresholds were utilized to determine the impact stress threshold has on RuTemp. Stress thresholds were adapted from Mader et al. (2010) and were classified as < 25 no stress, 26 to 30 mild, 31 to 35 moderate, 36 to 40 severe, 41 to 45 extreme, and > 46 extreme danger. The CCI values were averaged by h and stress thresholds assigned.

STATISTICAL ANALYSIS

Prior to the analysis of RuTemp, hourly average and maximum RuTemp were determined for an individual animal and used for the analysis of TOD, season and stress threshold. The GLIMMIX procedure of SAS (SAS 9.4; SAS Inst. Cary, NC) was used to analyze RuTemp, AUC, and lag time. Animal was the experimental unit, d was the repeated measure, and for steers, pen was used as the random effect. The model statement included the season × TOD and season × stress threshold interactions for RuTemp, AUC, and lag time. The RuTemp to CCI ratio were calculated using REG procedure of SAS where daily average CCI was regressed on RuTemp for individual animals. The equation and slope of the line were used to calculate the ratio.

Differences were declared significant when $P < 0.05$ and declared a trend when $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Steers.

There was a season × TOD interaction for average and maximum RuTemp ($P < 0.001$; Table 2). Lowest average and maximum RuTemp were observed in the AM period for both the spring and summer periods. Highest average RuTemp were observed in the E-PM and PM in the summer season. Mader (2002) reported CBT of feedlot cattle was highest between 1400 to 2100 h and decreased between 0000 and 0800 h. The highest maximum RuTemp were observed in the E-PM and PM in the summer and PM in the spring ($P < 0.001$). According to Mader (2002), peak metabolic heat production from ruminal fermentation occurs approximately 4 to 6 hr after feeding. In feedlot diets with a higher percentage of fermentable starch, this lag time may be less. Steers in the current experiment were fed at approximately 0700 and 1300 hr daily. Based on the fermentation lag time, peak fermentation would have occurred during the PM period when environmental conditions were elevated and potential contributed to the overall heat load of the steers.

There was a season × TOD interaction for AUC $\geq$ 39.4 (P < 0.001), 40.0 (P < 0.001), and 41.1 °C (P < 0.001; Table 2). Steers spent the greatest percentage of time with RuTemp $\geq$ 39.4°C in the spring in the E-AM, AM and PM, $\geq$ 40.0 and $\geq$ 41.1°C in the E-PM and PM period in the summer. Generally, steers spent the greatest percentage of time with an elevated RuTemp during the E-PM or PM and the least in the AM period in both spring and summer. This indicates that cooling may have been inadequate until the early AM for the steers. In feedlot cattle, nighttime cooling is achieved when ambient temperatures are lower than their CBT. When ambient temperatures are greater than CBT, heat transfer is reversed and heat load of the animal increases. During extended heat waves when environmental conditions do not decrease, CBT has potential to increase to dangerous levels. Gaughan and Mader (2014) reported that after a major heat event, cattle had elevated respiration rates at 0600 h. Although respirations rates were not observed in the current experiment, it can be assumed that steers would have used this method to dissipate excess heat load. Mader and Kreikemeier (2014) reported a 0.06°C increase in feedlot heifers temperatures and Liang et al. (2013) reported a 0.30°C increase in RuTemp in dairy cows in the summer compared to spring. In the current experiment, the average CCI for spring was 19.4 and 28.1 for summer, which could have been one of the factors contributing to elevated RuTemp.

For average ($P < 0.001$) and maximum ($P < 0.001$) RuTemp, there was a season × stress threshold interaction ($P < 0.001$; Table 3). When environmental conditions were characterized as No Stress, the lowest average and maximum RuTemp were observed. There was a 0.13 and 0.50°C increase in RuTemp in No Stress compared to Extreme conditions for spring and summer, respectively ($P < 0.001$). As environmental conditions increased in severity, the heat gradient may be reversed and potentially transfer to the animal increasing heat load. Within the CCI equations, radiating heat from pen surfaces are taken into consideration. The surfaces surrounding the animals are considered as additional heat emitters and also contribute to heat load of the steers (Mader et al., 2010). In the current experiment, steers were housed in soil-surfaced pens without shade. Even without direct exposure to solar radiation, pen surfaces may emit heat overnight. The lack of heat transfer to pen surfaces overnight may reduce the ability of the animal to dissipate their excess heat from the d and may have been a factor contributing to increased RuTemp. The addition of a shade structure may have provided the steers an opportunity to avoid some direct radiant heat and provide them a means to manage CBT in extreme conditions.

There was a season × stress threshold interaction for lag time ($P < 0.001$). The lag times generally decreased as severity of environmental conditions increased. Within stress threshold, summer lag times were always shorter than spring lag times ($P < 0.001$). Limited research is available that defines the lag time of heat stressed cattle in a feedlot setting. Previous research has used lag time to determine the rate of digestion, onset of fever, or exposure to disease, but not animal response to ambient temperatures. Although, some previous research has shown that maximum respiration rates are observed approximately 4 h after maximum ambient temperature exposure (Gaughan et al., 2002; Gaughan and Mader, 2014). In the present experiment, lag time in the summer was 1.89 h. This may suggest that there is an additional lag time between when maximum RuTemp and elevated respiration rates. Understanding lag times may aid in assessing thermal heat load of the animal and when maximum CBT of the animal may occur. Additional research is needed to investigate how shade and other heat mitigation methods impact the lag time for maximum RuTemp and elevated respiration rates.

During the summer, the ratio of RuTemp:CCI ratio decreased (0.51 C: 1 CCI in comparison to the spring's ratio (0.56°C: 1 CCI). Indicating that during the summer, RuTemp increases at a faster rate than spring. Overall, the RuTemp to CCI ratio for steers were 0.53°C: 1 CCI. Currently, limited research is available that defines the rate at which RuTemp increases with increasing CCI or ambient temperatures. Additional research would be beneficial in understanding how RuTemp reacts to environmental conditions. In the current experiment, data was only collected during spring and summer. While extensive research is available that assess the effect of heat stress on cattle, additional research is still needed to determine how cattle react to cold stress conditions. Previous data quantifying the effects of CCI threshold on CBT is limited. Although previous research has reported a positive relationship between ambient temperatures and body temperature of feedlot cattle, Brown-Brandl et al. (2005) found that as ambient air temperatures increased, CBT of steers increased, especially when ambient temperatures were greater than CBT of the animal. In the current experiment, similar results were observed between CCI and RuTemp. As daily CCI increased, average (R^2 = 0.57; Figure 1a) and maximum (R^2 = 0.49; Figure 1b) RuTemp increased. Aside from assessing comfort level of cattle, range in temperature with in the CCI thresholds can be utilized to determine potential daily effects of climate change and can aid in appropriate management techniques. Additional research is needed to observe the effects of CCI stress thresholds on respirations rates as well as CBT.

Heifers.

There was a season × TOD interaction for average (P < 0.001) and maximum (P < 0.001) RuTemp (Table 2). Average RuTemp were highest in PM period in the summer followed by the summer AM period. During the spring, average RuTemp were lowest during the AM period. Rumen temperatures were generally lower in the AM and E-AM period than E-PM or PM periods for both seasons. Maximum RuTemp were highest during the summer in the PM and lowest maximum RuTemp were observed in spring during the AM. There was a season × TOD interaction for AUC ≥ 39.4, 40.0, or 41.1°C (P < 0.001). Heifers spent the greatest amount of time with RuTemp ≥ 39.4 or 40.0°C in the PM period of summer and the least in the AM during spring. When evaluating the effects of summer conditions on the RuTemp of pregnant, black-hided, beef cows, Boehmer et al. (2015) observed similar results. When exposed to elevated ambient temperatures, RuTemp of the cows were highest in the evenings and early mornings and lowest later in the morning, similar to the present experiment (Boehmer et al., 2015). When comparing environmental conditions for spring compared to summer, solar radiation increased by 26% and air temperature by 43%. In addition to increased environmental conditions, average RuTemp increased by 0.31°C and maximum RuTemp by 0.39°C. In dairy cows, Ammer et al. (2016) reported a greater rectal temperature

(40.4°C) in the summer; Liang et al. (2015) reported RuTemp an increase of 0.40°C in summer and Boehmer et al. (2015) reported an increase of 2.70°C in pregnant beef cows. Thermal heat load of cattle are impacted by environmental conditions, especially with summer conditions. Understanding the impact environmental conditions have on CBT of cattle in a pasture setting will aid in providing mitigation to reduce heat load.

There was a season × stress threshold interaction for average and maximum RuTemp ($P < 0.001$; Table 3). Highest average RuTemp when observed CCI conditions were characterized as Moderate to Extreme in the summer and least in the spring when No stress conditions were present. Unfortunately, there is limited research on the impact of stress threshold on CBT of heat stressed heifers. Although, previous research has indicated that when replacement heifers or cows were exposed to extreme environmental, a decrease in estrous length, pregnancy rates, and gestation were observed (Amundson et al., 2006; Boehmer et al., 2015; Cooper-Prado et al., 2011). In the current study, the increased exposure of heifers to environmental conditions at increasing severity, may harm their reproductive success. Additional research is needed to investigate the impact environmental conditions characterized by the CCI stress threshold on pregnancy rates and gestation length in beef or dairy cattle.

There was a season × stress threshold interaction ($P < 0.001$) for lag time (Table 3). When environmental conditions were characterized as No Stress in the spring, the longest lag time was observed and the shortest lag time when conditions were characterized as Extreme. Ammer et al. (2016) used the temperature humidity index (**THI**), to evaluated rectal temperatures in dairy cows. In comparison to the CCI, the THI is an index that uses the interaction between ambient air temperature and relative humidity to describe the environmental conditions cattle maybe experiencing. In dry dairy cows, average daily rectal temperatures were positively correlated with average daily THI values ($R^2 = 0.30$). Similarly, the current experiment average daily RuTemp were positively correlated with CCI values ($R^2 = 0.73$; Figure 1c) indicating that as CCI increases, RuTemp also increases. As CCI increases, the RuTemp and heat load of the heifers also increase. During the development of the index, values < 25 were established as the lower end of the stress threshold and were found to be similar to CBT of cattle, did not affect respiration rates, and allowed adequate overnight cooling (Mader et al., 2010). Based on the CCI stress thresholds, heifers in the current experiment were exposed to mild to severe conditions during the period. The ability of cattle to maintain a constant RuTemp is compromised when environmental variables are higher than the temperature of the animal which may reverse the transfer of heat back to the hide of the animal (Dikmen and Hansen, 2009; Boehmer et al., 2015).

In the summer, RuTemp:CCI was greater (0.46°C:1 CCI; Table 5) than spring (0.73°C : 1 CCI). In previous experiments, Kaufman et al. (2018) reported that afternoon predicted vaginal temperatures increased by 0.15 and 0.22°C per unit of THI. In beef heifers, the ratio of ambient air temperatures to CBT has not been well defined. Additional research is needed to investigate the impact of body composition on RuTemp. As beef or dairy cattle mature, their susceptibility to heat stress also increases, especially during periods of high production. During pregnancy or lactation, increased metabolic heat production, increased feed intakes, and milk production may increase the animal's sensitivity to environmental conditions and may impact heat load (Liang et al., 2012; Ammer et al., 2016).

IMPLICATIONS

The results of this experiment indicate that environmental conditions characterized by CCI stress thresholds influence RuTemp in beef cattle. The addition of continuous RuTemp monitoring is beneficial to assess the thermal heat load animals may be experiencing. Being able to remove the impact of environmental conditions from CBT will identify cattle experiencing illness prior to physical symptoms being exhibited. In younger cattle may aid in fever monitoring with disease treatment protocols. During severe or extreme environmental conditions, if an animals RuTemp is greater than average predicted RuTemp, it may be an indicator that the animal may be experiencing illness. Rumen temperature monitoring may also be utilized in assessing heat stress susceptibility in individual animals and be able to identify which animals may be struggling or need addition help reducing heat load. Results observed in the present experiment indicate that RuTemp are influenced by environmental conditions in the spring and summer season. During heat stressed conditions, use of CCI has potential to be used to predict changes in RuTemp. Predicted RuTemp will provide opportunity to identify animals that are experiencing thermal stress or account for environmental conditions during identification of disease or reproduction activities.

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Table 4.1: Environmental conditions from the Oklahoma Mesonet

	Season[2]							
	Spring				Summer			
Time of d[1]	E-AM	AM	E-PM	PM	E-AM	AM	E-PM	PM
Stilwater[3]								
Air Temperature, ºC	20.7	17.9	22.0	25.0	23.4	19.4	24.0	28.6
Relative Humidity, %	76.3	85.3	72.6	62.7	69.9	83.8	65.9	49.0
Solar Radiation, w/m^2	0.2	17.2	433.7	459.7	1.5	11.2	491.2	547.6
Wind Speed, m/hr	2.9	2.7	4.3	4.7	2.4	2.0	3.4	3.9
Rain fall, cm	0.23	0.19	0.08	0.34	0.14	0.14	0.12	0.03
CCI[6]								
Average	19.4	16.2	22.5	25.8	23.1	19.4	26.3	30.7
Maximum	30.5	29.1	37.0	38.5	39.8	33.3	47.0	46.4
Fort Supply[4]								
Air Temperature, ºC	15.0	11.8	14.1	19.5	25.9	22.5	26.0	31.1
Relative Humidity, %	71.3	83.1	74.5	54.9	68.7	81.1	69.0	50.2
Solar Radiation, w/m^2	0.3	11.3	322.2	475.6	1.1	26.9	443.1	622.0
Wind Speed, m/hr	3.7	3.5	4.0	4.6	3.1	3.2	3.7	4.1
Rain fall, cm	0.29	0.17	0.28	0.26	0.13	0.28	0.12	0.15
CCI								
Average	9.6	5.2	10.8	18.5	24.0	20.1	27.3	33.6
Maximum	30.9	23.2	35.0	36.6	38.5	31.1	45.1	48.3

[1]Four 6 hr periods based on exposure to solar radiation. Early morning (E-AM) – 00:00 to 05:59; Morning (AM) – 06:00 to 11:59; Afternoon (E-PM) – 12:00 to 17:59 and Evening (PM) – 18:00 to 23:59.
[2]Spring – March 1 to May 30 and Summer – June 1 to August 31.
[4]May to August 2013.
[5]March to August 2015.
[6]Comprehensive climate index adapted from Mader et al. (2010).

Table 4.2: Effects of time of day (TOD[1]) and season[2] on rumen temperature (RuTemp) and comprehensive climate index (CCI[3])

	Season									
	Spring				Summer					P-Value
TOD	E-AM	AM	E-PM	PM	E-AM	AM	E-PM	PM	SEM	Season × TOD
Steers[4]										
RuTemp, °C										
Average	40.06[d]	39.56[f]	40.07[d]	40.24[b]	40.14[c]	39.64[e]	40.44[a]	40.45[a]	0.04	<0.001
Maximum	40.16[e]	39.72[g]	40.34[c]	40.45[b]	40.26[d]	39.84[f]	40.70[a]	40.70[a]	0.04	<0.001
AUC, %[3]										
≥ 39.4 °C	89.79[a,b]	59.30[g]	77.51[e]	87.28[c]	88.82[b]	61.75[f]	85.64[d]	89.80[a]	1.46	<0.001
≥ 40.0 °C	59.95[e]	25.98[h]	56.15[f]	68.55[c]	64.86[d]	32.79[g]	71.28[b]	76.17[a]	2.12	<0.001
≥ 41.1 °C	4.70[f]	0.78[h]	9.65[d]	11.92[c]	7.25[e]	1.88[g]	24.89[a]	20.38[b]	0.96	<0.001
Heifers[5]										
RuTemp, °C										
Average	38.83[e]	38.74[g]	38.77[f]	38.92[d]	39.22[b]	38.90[d]	38.94[c]	39.48[a]	0.01	<0.001
Maximum	38.89[e]	38.76[g]	38.81[f]	38.97[c,d]	39.39[b]	38.95[d]	39.01[c]	39.66[a]	0.02	<0.001
AUC, %										
≥ 39.4 °C	1.28[f]	0.23[h]	0.36[g]	3.81[e]	29.90[b]	6.80[c]	5.34[d]	56.69[a]	1.13	<0.001
≥ 40.0 °C	0.32[e]	0.00[f]	0.00[f]	0.25[e]	8.04[b]	0.76[d]	1.34[c]	13.14[a]	0.82	<0.001
≥ 40.6 °C	0.00[d]	0.00[d]	0.00[d]	0.00[d]	1.83[b]	0.25[c]	0.27[c]	2.06[a]	0.26	<0.001

[a-h] Values with unique superscripts differ due to a Season x TOD interaction when $P < 0.05$.
[w-z] Values with unique superscripts differ due to a TOD effect when $P < 0.05$.
[m-n] Values with unique superscripts differ due to a Season effect when $P < 0.05$.
[1]Four 6 hr periods based on exposure to solar radiation. Early morning (E-AM) – 00:00 to 05:59; Morning (AM) – 06:00 to 11:59; Afternoon (E-PM) – 12:00 to 17:59; Evening (PM) – 18:00 to 23:59.
[2]Spring – March 1 to May 30. Summer – June 1 to August 31.
[3]Area under the curve calculated as AUC = ((Current time) – (lag time) x (current rumen temperature) + (lag rumen temperature))/2. Percentage calculated as % = ((Above AUC)/(Daily AUC) * 100).
[4]Steers house in open aired, feedlot pens from May to August 2013 in Stillwater Oklahoma.
[5]Heifers house in a native rangeland pasture (43 ha) from March to July 2015 at Fort Supply Oklahoma.

Table 4.3: Effect of comprehensive climate index stress threshold[1] and season on rumen temperature (RuTemp) and lag time[2]

	Spring					Summer						*P*-Value
	No stress	Mild	Moderate	Severe	Extreme	No stress	Mild	Moderate	Severe	Extreme	SEM	Stress × Season
Steers[3]												
RuTemp, °C												
Average	39.85^{e}	40.25^{c}	40.07^{d}	39.97^{d}	39.98^{d}	39.90^{e}	40.13^{d}	40.53^{b}	40.78^{a}	40.40^{c}	0.02	<0.001
Maximum	39.99^{c}	40.46^{b}	$40.30^{b,c}$	$40.30^{c,b}$	40.32^{e}	40.08^{c}	40.31^{b}	40.75^{c}	41.04^{b}	41.74^{a}	0.07	<0.001
Lag time, hr	4.83^{a}	4.61^{b}	4.32^{b}	2.85^{c}	1.23^{e}	2.83^{c}	2.72^{c}	1.62^{d}	1.12^{f}	1.16^{f}	0.008	<0.001
Heifers[4]												
RuTemp, °C												
Average	38.30^{e}	38.46^{d}	38.61^{b}	39.26^{a}	39.30^{a}	38.44^{d}	38.63^{b}	39.27^{a}	39.25^{a}	39.30^{a}	0.02	<0.001
Maximum	38.91^{c}	38.76^{d}	38.64^{d}	39.31^{b}	$39.35^{a,b}$	39.08^{e}	39.15^{e}	39.44^{a}	39.31^{b}	39.40^{a}	0.02	<0.001
Lag time, hr	8.84^{a}	6.81^{b}	4.68^{c}	3.69^{d}	2.36^{f}	3.76^{d}	3.27^{e}	3.22^{e}	2.67^{g}	2.11^{h}	0.33	<0.001

[a-h] Values with unique superscripts differ due to a Season x Stress interaction when $P < 0.05$.

[1]CCI stress thresholds adapted from Mader et al. (2010). No stress - > 25; Mild – 25 to 30; Moderate – 30 to 35; Severe – 35 to 40; Extreme – 40 to 45.

[2]Time difference between peak CCI and peak rumen temperature in a 24 hr period.

[3]Steers housed in open aired, soil surface feedlot pens from May to August 2013 in Stillwater Oklahoma.

[4]Heifers housed in native rangeland pasture (43 ha) from March to July 2015 in Fort Supply Oklahoma.

Table 4.5: Ratio[1] of comprehensive climate index (CCI[2]) and rumen temperature (RuTemp[3])

	Season[4]		
Item	Spring	Summer	Overall
Steers[5]			
CCI:RuTemp	3.53	2.71	3.10
RuTemp:CCI	0.56	0.37	0.53
Heifers[6]			
CCI:RuTemp	3.76	2.54	3.12
RuTemp:CCI	0.73	0.39	0.60

[1]Individual animal's daily average rumen temperatures were regressed with daily average CCI. The equation of the line were used to calculate the ratio.
[2]CCI equations were adapted from Mader et al. (2010).
[3]Daily rumen temperatures for individual animals were used for the calculation.
[4]Spring – March 1 to May 31 and Summer – June 1 to August 31.
[5]Steers were housed in opened air feedlot pens from May to August 2013 in Stillwater, Oklahoma.
[6]Heifers were housed in native rangeland pastures (43 ha) from March to July 2015 in Woodward, Oklahoma.

FIGURE CAPTIONS

Figure 4.1: Relationship of rumen temperature and comprehensive climate index (CCI)

4.1a: Daily average CCI and daily average rumen temperature of steers. 4.1b: Daily maximum CCI and average of individual daily maximum rumen temperatures of steers. 4.1c: Daily average CCI and daily average rumen temperature of heifers. 4.1d: Daily maximum CCI and average of individual daily maximum rumen temperatures of heifers. CCI stress thresholds were adapted from Mader et al (2010). > 25 – No stress; 25 to 30 – Mild; 30 to 35 – Moderate; 35 to 40 – Severe; 40 to 45 – Extreme; > 45 – Extreme danger. Steers were housed in open aired, feedlot pens from May to August 2013 in Stillwater Oklahoma. Heifers were housed in a native rangeland pasture (43 ha) from March to July 2015 in Woodward Oklahoma.

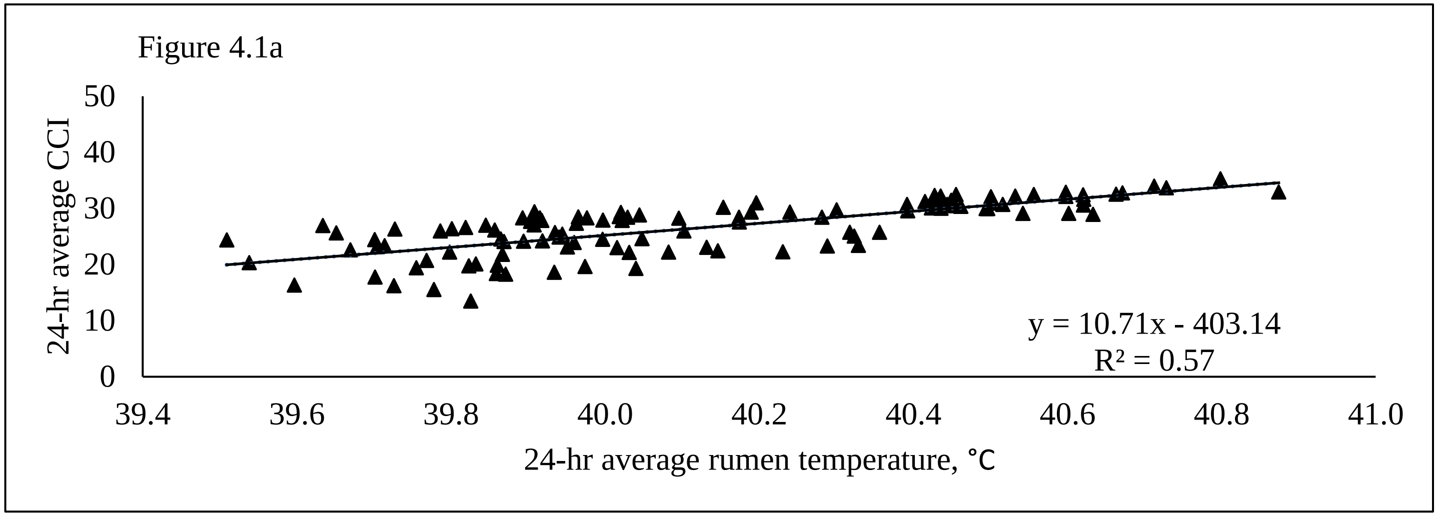
Figure 4.1a
24-hr average CCI
50
40
30
20
10
0
39.4
39.6
39.8
40.0
40.2
40.4
40.6
40.8
41.0
24-hr average rumen temperature, °C
y = 10.71x - 403.14
R² = 0.57

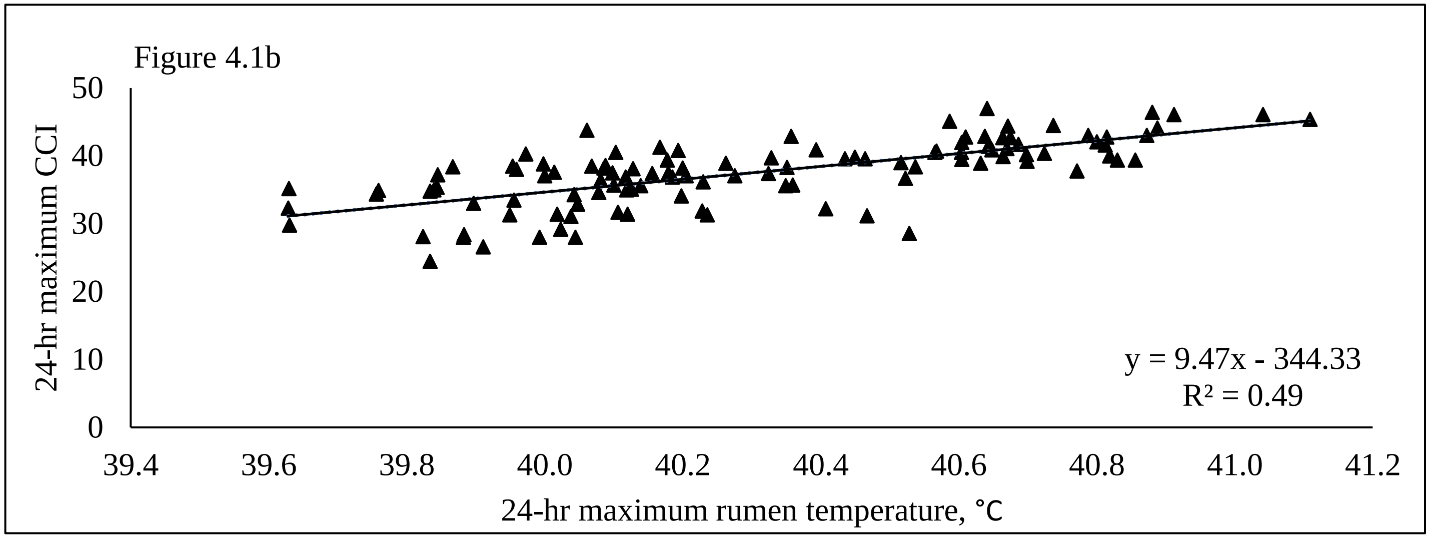
Figure 4.1b
24-hr maximum CCI
50
40
30
20
10
0
39.4
39.6
39.8
40.0
40.2
40.4
40.6
40.8
41.0
41.2
24-hr maximum rumen temperature, °C
y = 9.47x - 344.33
R² = 0.49

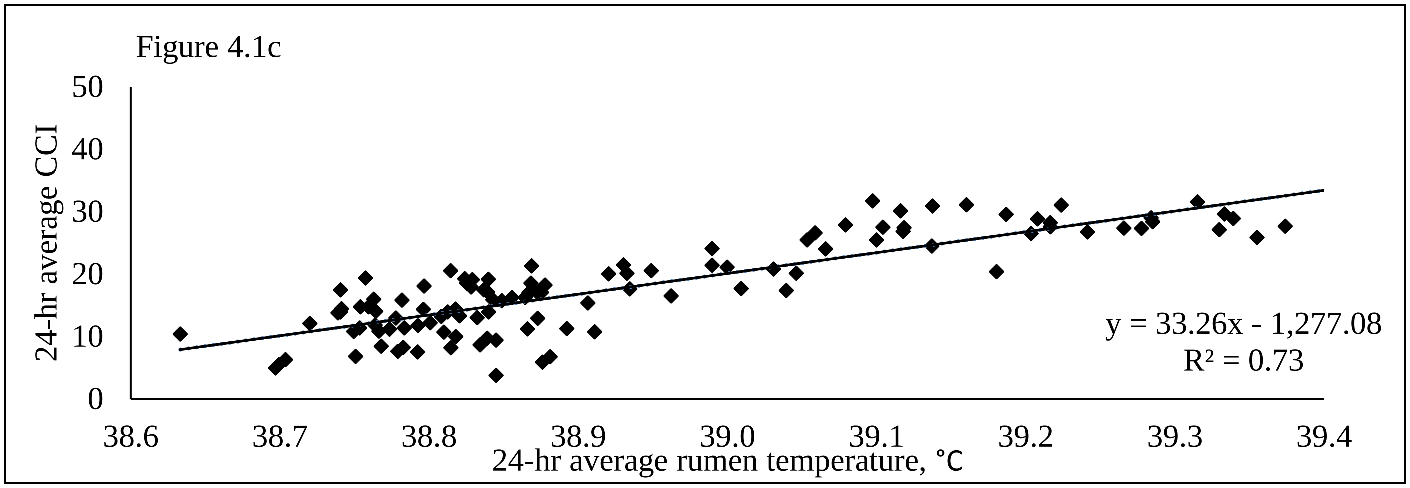
Figure 4.1c
50
40
30
20
10
0
24-hr average CCI
38.6
38.7
38.8
38.9
39.0
39.1
39.2
39.3
39.4
24-hr average rumen temperature, °C
y = 33.26x - 1,277.08
R² = 0.73

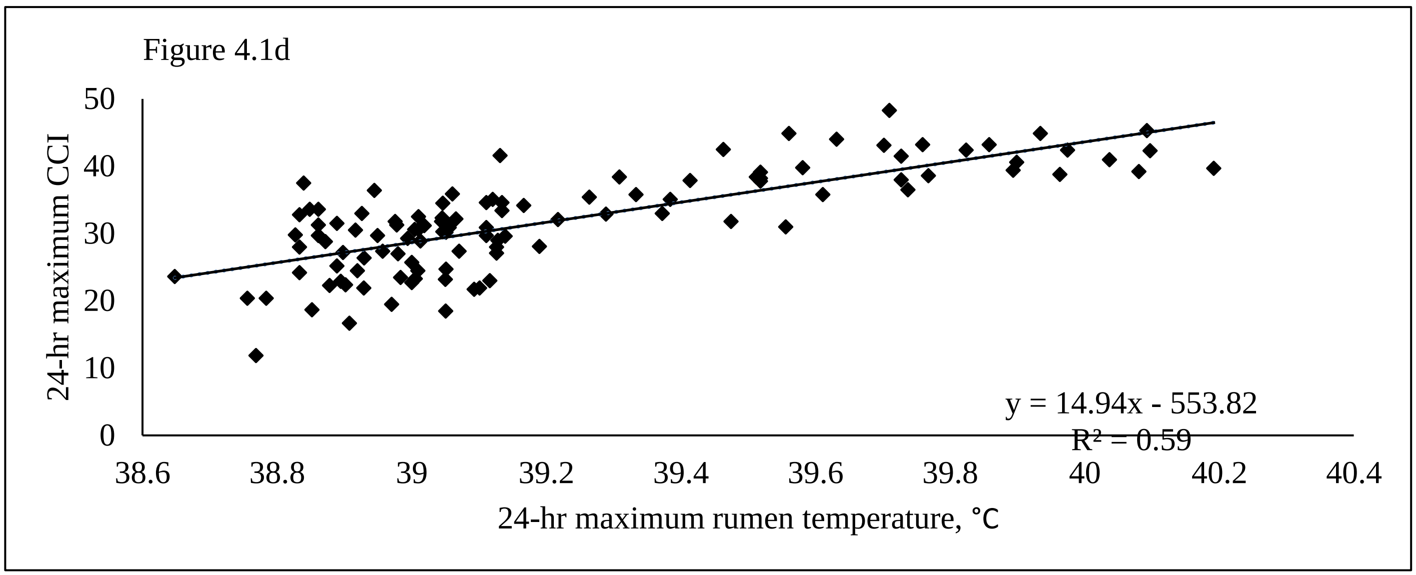
Figure 4.1d
50
40
30
20
10
0
24-hr maximum CCI
38.6
38.8
39
39.2
39.4
39.6
39.8
40
40.2
40.4
24-hr maximum rumen temperature, °C
y = 14.94x - 553.82
R² = 0.59

Running head: Water intake of beef cattle

CHAPTER V

RUMEN TEMPERATURE AS A PREDICTOR OF WATER INTAKE

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ABSTRACT

Fifty-four (**Exp. 1**; arrival BW = 391 $\pm$ 13 kg) and seventy-two (**Exp. 2**; arrival BW = 380 $\pm$ 18 kg) black-hided, crossbred steers were used in an experiment to predict daily water intake (**DWI**) of feedlot steers. Steers in Exp. 1 were housed in the Insentec Monitoring System (**InSt**; Markenesse, Netherlands) where feed and water intake was recorded for individual animals daily. The known water intakes for steers in Exp. 1 were used to create a DWI prediction equation. Steers in Exp. 2 were housed in open-air, soil-surface, feedlot pens and were used to demonstrate the use of the prediction equation developed in Exp. 1. Using the difference between hourly maximum and real-time RuTemp, individual drinking events were identified within the RuTemp observations. For each drinking event, deviation between temperatures were summed daily to calculated total temperature deviation (**TotDev**). The variables, TotDev, DMI, water temperature (**WaTemp**), and daily comprehensive climate index (**CCI**) were used to predict DWI. Across all of the variables, the largest R^2 (0.35) were obtained from the following equation: DWI = -56.04 + 1.41(WaTemp) + 1.59(DMI) + 0.76(CCI_{ave}) + 0.50(CCI_{max}) + 0.23 (TotDev). Average predicted DWI were 51.52 L and 45.44 L for steers in Exp. 1 and 2, respectively. Daily average CCI values were categorized into 1 of 4 stress thresholds (no stress, mild, moderate, and severe) to determine impact environmental conditions have on DWI. As CCI stress threshold increased, DWI increased (*P* < 0.001) and DMI decreased (*P* = 0.02). The ratio of DWI/DMI increased as CCI stress threshold increases and in no stress conditions, ratio was 3.59 L/1 kg and 5.73 L/ l kg for severe conditions (*P* = 0.001). Daily water intake had a strong relationship with daily average CCI (R^2 = 0.43), TotDev (R^2 = 0.43), and WaTemp (R^2 = 0.36). Results from this experiment prove that WaTemp, DMI, CCI, and TotDev influence DWI in feedlot steers. As CCI stress threshold increases, DWI increased and DMI decreased. Continuous RuTemp monitoring has potential to predict DWI in feedlot steer.

Keywords: comprehensive climate index, daily water intake, feedlot, heat stress, rumen temperature, water temperature

INTRODUCTION

Adequate water is needed for the regulation of body temperature, adequate growth, digestion, and lubrication of joints of beef cattle (NASEM, 2016). Daily water intake (**DWI**) of feedlot cattle has been well documented in the past 30 years (Hicks et al., 1988; Arias and Mader, 2011). Previous equations include the influence of DMI, ambient temperature, precipitation, solar radiation, and dietary salt on DWI of cattle. Summer environmental conditions increase DWI compared to spring conditions by 3.10 to 15.1 L/d (Hicks et al., 1988; Arias and Mader, 2011).

Interactions between various environmental factors influence the environment surrounding the animal and may affect performance, DMI, and DWI. Mader et al. (2010) created an environmental index called the Comprehensive Climate Index (**CCI**). The CCI incorporates the interactions between several environmental variables including solar radiation, ambient temperature, and wind speed. Stress thresholds were developed based on the severity of environmental conditions and are used to assess heat stress conditions for cattle. Additional research is needed to determine the impact increasing stress thresholds have on DMI and DWI.

Predicting water intake of individually fed cattle versus pen fed may result in altered drinking or eating behavior that my influence results (Brew et al., 2011). Through recent advancements in technology, group-feeding systems have proven effective in recording individual DMI and DWI. The Insentec Monitoring System (**InSt**; Insentec, Markenesse, Netherlands) has been proven an effective instrument for monitoring individual feed and water intake for feedlot cattle (Allwardt et al., 2017; Maxwell, 2013).

The use of recticulo-rumen temperature boluses (**RuTemp**) allows for continuous monitoring and may be used to monitor various physiological conditions including respiratory diseases, acidosis, and heat stress (Haviland, 2015; Rose-Dye et al., 2011; Wahrmund et al., 2012). Depending on water temperature and quantity of water intake, RuTemp decrease dramatically and may take 20 to 120 min to return to pre-drinking temperatures (Bewley et al., 2008). Currently, limited research is available that defines the quantity of a drinking event based on changes in RuTemp. Based on changes in RuTemp due to individual drinking events, DWI of individual steers could be predicted. The objective of this experiment is create an equation to predict DWI of individual feedlot steers based on changes in RuTemp due to the drinking events.

MATERIALS AND METHODS

All protocols were approved by the Oklahoma State University Institutional Animal Care and Use Committee.

Cattle Management.

Fifty-four (**Exp. 1**; arrival BW = 391 ± 13 kg) black-hided steers were used to develop an equation to predict individual animal water intake from RuTemp. Water intake for seventy-two (**Exp. 2**; arrival BW = 380 ± 18 kg) black-hided, crossbred steers were predicted from the equation developed in Exp. 1 and evaluated against previous water intake equiations. All steers arrived at Willard Sparks Beef Research Center in May 2013. The morning after arrival, steers were weighed individually, given a numbered ear tag. Steers in Exp. 1 were sorted by BW into 1 of 4 pens to begin a 14-d training period to learn to use automated bunks. At the end of training period, steers were weighed individually, and based on d-1 BW, randomly allocated to 1 of 2 experimental treatments. Steers in Exp. 2 were randomly allocated based on d -1 BW to 1 of 3 experimental treatments.

Experimental treatments included natural, conventional, and conventional with a β-adrenergic agonist (**βAA**). The natural treatment did not receive an implant, ionophores, or antibiotics throughout the experimental period. Upon allocation to home pens, all conventional steers received a 40 mg of estradiol and 200 mg of trenbolone acetate (TBA; Revelor-XS; Merck Animal Health, Desoto, KS) and 33 mg/kg feed monensin and 9 mg/kg feed tylosin phosphate (Rumensin and Tylan, respectively; Elanco Animal Health; Greenfield, IN) daily in a dry pelleted supplement. During the last 20 d (with a 3 d withdrawal), conventional steers with βAA were fed zilpaterol hydrochloride (Zilmax; Elanco Animal Health) at a rate of 6.8 mg/kg feed in a dry pelleted supplement. All steers were fed at approximately 0700 and 1300 h daily in the following order to eliminate treatment cross contamination, natural, conventional, and conventional with βAA. The finishing diet consisted of dry-rolled corn, switch grass hay, dried distillers grains, corn gluten feed, and a liquid and dry supplement. All steers were fed the same base diet and depending on experimental treatment, the dry pelleted supplement differed. Additional diet formulation, cattle management, feedlot performance, and carcass characteristics can be found in Maxwell et al. (2015).

Steers in Exp. 1 were housed in the Insentec monitoring system (**InSt**; Insentec, Markenesse, Netherlands). Within the InSt barn, 2 experimental treatments were represented; natural (2 pens; 13 to 14 steers/pen) and conventional with βAA (2 pens; 13 to 14 steers/pen). Pens in the InSt were 11.90 x 30.50 m soil-surfaced feedlot pens with a 6.10 m cement pad with a solid, shade awning covering the bunks and cement pad. Bunks in InSt are programmed for quantification of feed and water intakes for individual steers. When the steers entered the bunk, time and bunk weight are recorded, when the steer exits the bunk, ending time and weight are recorded. Feed and water intake data is communicated to a main computer located within the barn. Each pen contained six automated feed bunks and one water bunk that were approximately 1.0 m x 0.8 m x 0.8 m. To record individual feed and water consumption, only one steer was allowed in the automated bunks at one time. Water bunks (1 bunk/pen) were programmed to contain approximately 35 to 40 L of water at all times. After steers exited a water bunk, all cattle were excluded from bunks for approximately 40 s to allow bunks to refill and stabilize prior to another steer entering the bunk. Steers had ad libitum access to all feed and water bunks. Water bunks were cleaned three times per week. Feed and water bunks within the barn were validated with a 22.7 kg ($\pm$ 1 kg) weight on the morning of all weigh days to ensure accuracy of system recordings.

Steers in Exp. 2 were housed in open air, soil surface, 12.2 × 30.5 m feedlot pens with a 12.2 m concrete feed bunk with a 76-L concrete fence-line water tank (Model J 360-F, Johnson Concrete, Hasting, NE) that was 1 m x 1 m in size. The waterer was located on the fence line shared between 2 pens and steers within 2 neighboring pens shared one waterer (n = 26 to 28) and approximately 0.04 m^2 of water space was provided per steer. Experimental treatments described for Exp. 1 were represented in outside pens (8 pens/treatment; 6 steers/ pen).

Data Collection.

Rumen temperature boluses (SmartStock; LLC, Pawnee, OK) were administered with an oral bolus gun to all steers on d 0. Steers in Exp. 1 received their boluses after their training period (May 21, 2013) and Exp. 2 received their boluses when they were allocated to their experimental pens (May 9, 2013). For Exp. 1, 113 d of RuTemp observation and InSt water intakes were used for the equation development. For Exp. 2, 127 d of RuTemp observations were used. Boluses were programmed to record RuTemp in 3-minute intervals and transmit RuTemp to a nearby receiver. Receivers were located on the fence line between adjacent pens and next to the feed bunk to ensure steers were within 9 m of a receiver at all times. For Exp. 1 and 2, water temperatures were recorded with boluses, similar to RuTemp boluses (**WaTemp**; SmartStock; LLC, Pawnee, OK). Boluses were place in waterers in InSt pens prior to steers being allocated to pens. Boluses were placed into a small plastic bottle with multiple perforations (to prevent damage or misplacement) in the middle of the water bunks located within each pen. Water temperature boluses were programmed to transmit water tank temperatures in 5 min intervals to the nearby receivers.

Equation Development.

All equations were development in R (R Core Team, 2018, v. 3.4.3).

For development of the equation, known water intakes from steers in Exp. 1 were used. Prior to model development, RuTemp prior to bolus administration, negative water or feed intakes and water intakes less than 1 L, due to cleaning or bunks refilling, were removed from the dataset. If individual drinks were recorded within 10 min of each other, they were assigned to one drinking event. For each drinking event, water intakes from each drink was summed, and time for the first drink was used for the dataset.

Individual drinking events (**IDE**) were assumed to cause a dramatic drop in RuTemp. Deviation in RuTemp from the projected RuTemp were calculated for the time period following each identified drinking event. If the difference in RuTemp was greater than 1.50% of the real-time RuTemp, an IDE was triggered. The difference in projected and real-time RuTemp was summed for each IDE and then IDE were summed within each d for total temperature deviation (**TotDev**). Quantity of IDE within a d, from RuTemp were compared to quantity of DDE recorded by InSt to validate IDE identified from RuTemp.

Dry matter was calculated daily for each steer. A daily estimate of BW was obtained by adding ADG*DOF to d 0 BW. Rumen volume (**RVol**) was estimated daily for individual steers based on calculated BW using the following equation from Church (1979; equation 1):

$$RVol = BW\ (kg)^{0.57}$$

For individual steers, the final dataset had a daily observation for TotDev, BW, RVol, environmental conditions, WaTemp, and DMI. To determine influence of all variables on DWI, linear modeling methods were used to regress all variables against the known DWI recorded by the InSt.

Equation Demonstration.

Rumen temperatures from Exp. 2 were used to estimate individual water intake of pen fed steers using the equation developed in Exp. 1. In Exp. 2, actual DWI of the steers is unknown. Water intake predictions from RuTemp were compared to predicted DWI from 2 published DWI equations:

$$\text{Eq. 1: DWI (L/d)} = -6.0716 + (0.70866 \text{ x MT}) + (2.432 \text{ x DMI}) - (3.87 \text{ x Prec.}) - (4.437 \text{ x DS})$$

$$\text{Eq. 2: DWI (L/d)} = 5.92 + 1.03 \text{ DMI} + 0.04 \text{ SR} + 0.45 \text{ Tmin}$$

Equation 1 was adapted from Hicks et al. (1988) where MT is maximum daily temperature (°C), DMI is feed intake (kg/d), Prec. is daily precipitation (cm), DS as dietary salt (%) Our diet contained 0.38% salt (Maxwell et al., 2015). Equation 2 is adapted from Arias and Mader (2011) where SR is solar radiation, T_{min} is daily minimum ambient temperature, and DMI as feed intake (kg/d).

Environmental Data.

Environmental conditions were collected for Stillwater, OK in continuous 5-minute intervals from the Oklahoma Mesonet (Mesonet.org). Based on equations outlined in Mader et al. (2010), CCI were calculated in 5-minute intervals. Daily average solar radiation (**SR**), rain fall (**RF**), relative humidity (**RH**), air temperature (**AT**), wind speed

(**WS**), and CCI were used to determine the impact of environmental factors on DWI and were used in the equation development.

Depending on daily average CCI, stress categories were assigned to each d to determine how DWI were influenced by environmental conditions. Based on daily average CCI, 1 of 4-stress categories were assigned; no stress (< 25), mild (26 to 30), moderate (31 to 35), severe (36 to 40), extreme (41 to 45), and extreme danger (> 46; Mader et al., 2010). In addition to average DWI for CCI stress categories, DWI:CCI were calculated. For individual animals, predicted DWI was regressed on average CCI; the slope of the linear regression was water intake per unit of CCI.

Statistical Analysis.

In Exp. 1, daily water intake was estimated by multiple regression. Independent variables were WaTemp, DMI, BW, RVol, SR, RF, RH, AT, WS, CCI, and TotDev.

In Exp. 2 the effect of environmental stress categories (no stress, mild, moderate, and severe) on predicted DWI were evaluated with the GLIMMIX procedure of SAS (SAS 9.4; SAS Inst. Cary, NC) were used. Steers was used as the experimental unit, d as the repeated measure, and pen as the random variable. The model statement included CCI stress category. Further, DWI was regressed on CCI using the REG procedure of SAS to directly evaluate the relationship of these two variables.

Differences were considered significant for both equation development, validation, and CCI stress thresholds when $P < 0.05$ and a trend when $0.05 < P \geq 0.10$.

RESULTS AND DISCUSSION

Experiment 1.

Environmental variable averages for Stillwater Oklahoma are included in Table 5.1.

Due to the lack of significance, DBW ($P = 0.99$) and RVol ($P = 0.68$) were not included in the equation analysis. Similarly, Sexson et al. (2012) found a negative relationship between BW and DWI. Indicating that BW, metabolic BW, or RVol does not influence DWI in feedlot cattle. Decreasing DWI with increasing BW can be contributed to changes in the composition of gain as feedlot cattle approach harvest, indicating that body protein requires more water than fat or adipose tissue (Sexson et al., 2012; Arias and Mader, 2011).

Variables and equation development are included in Table 2. For both equations, water temperature ($P = 0.001$), DMI ($P = 0.001$) and TotDev ($P = 0.001$) contributed to the model and were kept in the equation. Of the environmental variables included in the equation, RF ($P = 0.08$) tended to contribute to the model and RH ($P = 0.81$) did not. In Arias and Mader (2011) utilized the temperature-humidity index (**THI**) within their model. The THI was the first environmental index developed to take into consideration the impact of RH on AT and adjusts the temperature accordingly (Arias and Mader, 2011; Sexson et al., 2012). Although, RH influenced DWI in previous prediction equations, it did not in the current. Steers in the current experiment were housed in a pen with a solid shade structure that may have contributed to a change in humidity within the pens. In previous experiments, steers have been housed in open-air or with soft shade structures that may allow for changes in the humidity around the animal. The use of the THI within a prediction equation is beneficial; however, not all environmental factors are taken into consideration. The CCI incorporates the interaction between all environmental factors that may impact the environment surrounding the animal.

In the current experiment, CCI was taken into consideration to account for the relationship between additional environmental variables. Mader et al. (2010) developed an environmental index to incorporate all of the variables into one continuous index. In the present study, daily average CCI (Fig 5.1c; $R^2 = 0.48$) and daily maximum CCI (Fig 5.1d; $R^2 = 0.39$) had a strong relationship with predicted DWI. Previous research has shown that with increasing ambient temperatures, DMI decreases and DWI increases (NASEM, 2016). Sexson et al. (2012) reported that as ambient temperatures increased, DWI increased in feedlot steers, similar to the present experiment. When substituting CCI for environmental variables within the present prediction equation, both daily average ($P = 0.001$) and maximum ($P = 0.001$) contributed to the model and reduced the number of variables in the equation (Table 5.2, equation 2). The CCI provides a relative indicator of the environmental conditions surrounding an animal and can be adjusted depending on geographical location, stage of production, or season. To account for the impact all environmental factors have on DWI of feedlot steers, average and maximum CCI were included in the model.

Using the dramatic drops in RuTemp has proven an effective means to identify IDE in feedlot steers. The number of predicted IDE with RuTemp deviations was 84.50% $\pm$ 37.00% of the InSt IDE for a steer d. Total deviation had a positive relationship with predicted DWI for the current experiment (Fig 5.1a; $R^2 = 0.48$). In the present experiment, WaTemp influenced DWI and RuTemp deviations ($P = 0.001$). In feedlot cattle, the change in RuTemp due to water intakes has not been well documented. Previously, the use of RuTemp monitoring observed similar results in dairy cattle. The magnitude of change in RuTemp along with the time it takes to return to a baseline temperature is affected by the temperature and quantity of the water the animal consumed (Bewley et al., 2008). In the present experiment, WaTemp influenced the prediction of DWI ($P < 0.001$) but were not strongly correlated with predicted DWI ($R^2 = 0.32$; Fig 5.1b). The relationship of WaTemp and TotDev ($R^2 = 0.035$; not shown) was weak compared to other variables used in the equation. Use of WaTemp in the current equation makes it distinctive and allows for modification depending on water source or season. The current water source experienced low variation in temperatures which many not be representative of all water sources. Although, it can be hypothesized that a combination between DMI, fermentation rates, or rumen fill may impact rumen volume which may affect the extent WaTemp has on RuTemp changes.

The relationship between DWI and DMI is weak compared to the relationship between other variables ($R^2 = 0.12$; not shown). Although steers in the present experiment were housed in a pen setting, their daily feed and water intakes were summed for individual animals. Previous experiments use weekly or daily DMI of steers penned individually or penned as a group. Arias and Mader (2011) and Hicks et al. (1988) found a positive relationship between DWI and DMI for pair fed steers, but no relationship between ambient temperature and DMI, depending on salt level and diet type. Diet type, roughage level, cattle size and environmental factors also impact DMI and should be taken into consideration. Steers in the present experiment were fed a high-concentrate diet in the summer months, the fermentation lag time could have impacted RuTemp and water intakes at those times. To account for the diurnal variation due to fermentation or environment, predicted RuTemp were used to identify water drinking events. Additional research is needed to assess the affect feed intake has on RuTemp of feedlot cattle and assess the need to develop DMI prediction equations to estimate changes in RuTemp.

Using deviations in RuTemp to predict DWI of feedlot steers predicted higher intakes than 2 other commonly used equations. the RuTemp method predicted 10.35 L/d more intake than Hicks et al. (1988) and 14.66 L/d more than Arias and Mader (2011). Hicks et al. (1988) equation is unique in predicting DWI based on weekly precipitation, dietary salt levels, and maximum ambient air temperatures and may be beneficial for cattle in a pen setting. Arias and Mader (2011) utilize the impact of minimum ambient temperature and solar radiation exposure to predict DWI. All of the equations are unique in their methods to predicting DWI of steers, although, the current equation can be tailored individual steers. Predicted DWI is beneficial in monitoring the health of the animal without inducing additional stress while moving the animal. Previously, RuTemp methods have been beneficial in the identification of fever in receiving calves prior to physical symptoms (Rose-Dye et al., 2011). Predicted DWI using RuTemp deviations may be beneficial in identifying fever, disease, or heat stress. Early identification of these symptoms will aid in reducing death loss, increase productivity, and decrease treatment costs.

Experiment 2.

As CCI increased, DWI increased ($P < 0.001$) and DMI decreased ($P = 0.02$; Table 5.4). When CCI was categorized as severe, DWI increased by 36.9% ($P < 0.001$) and DMI decreased by 2.90% when compared to no stress. In feedlot cattle, elevated DWI during the summer months is associated with increased heat dissipation by evaporative cooling through respiration or sweating. Thus, dehydrating cattle during times of heat stress is detrimental to their overall health, production, and wellbeing (NASEM, 2016). Previously, the impact of environmental conditions on DWI have been well-documented (Hicks et al., 1988; Hoffman and Self, 1972; and Mader and Davis, 2004). Hicks et al. (1988) and Hoffman and Self (1972) reported that water intake of cattle was impacted by season and summer increased DWI by approximately 7.8% compared to winter or fall. Arias and Mader (2011) reported an 87.3% increase in water consumed by cattle finished in the summer compared to those finished during winter months. Similar to previous experiments, predicted DWI of steers in the present experiment has a strong relationship with average daily CCI (R^2 = 0.48). Previous research has focused on the effects of ambient air temperature but not the relationship between all environmental variables that cattle experience daily. As CCI increases, SR, AT, and RH also increase increasing the severity of the surrounding environment for the animal. In addition to SR, AT, and RH, pen surface temperatures have a significant impact on cattle well-being and a strong relationship to DWI (R^2 = 0.70; Mader et al., 2010). With the CCI equations, SR is adjusted to include ground surface temperature. Steers in the present experiment were housed in open pens with direct SR exposure, the addition of a shade structure could have impacted exposure and reduced predicted DWI. To account for additional water loss during heat stress, increased water intake by the animal is required to account for evaporative cooling. The use of RuTemp to predict water intake takes into consideration elevated RuTemp due to heat stress conditions through the use of predicted temperatures.

Stress threshold had an impact on the ratio of DWI to DMI (P = 0.01; Table 5.4). As stress threshold moved from severe to no stress, the ratio of water to feed increased by

37% (P = 0.01). In the severe category, steers required 5.73 L of water for every kg of feed and 3.59 L/kg of water in no stress category (P = 0.01). Previous research has documented a lower L/kg ratio. Hicks et al. (1988) reported a 1.40 to 3.33 L/kg increase in as temperatures increased from 4.44 to 32.22°C and Arias and Mader (2011) reported a 3.38 L/kg in the summer season. In the present experiment, maximum ambient air temperature that steers were exposed to were approximately 29.44 to 35.00 °C, similar to previous studies.

In the present experiment, DMI and predicted DWI were poorly related (R^2 = 0.21; not shown). The relationship between DMI and DWI has been well documented. The NASEM (2016) states that the relationship between DWI and DMI may be low but water is still needed for proper diet digestion and passage through the rumen. Although, when over consumption of water occurs, passage rate increases and diet digestibility decreases and the opposite is seen in restriction situations. When water was removed for a 48-h period, cattle receiving a high-concentrate diet (similar to the present experiment) had a 44% decrease in feed intake indicating that when water intake is deprived, DMI is impacted (NASEM, 2016). Steers in the present experiment may have consumed more water than required which may have decreased their digestibility, especially in high-heat situations when DMI is reduced. Providing adequate water for heat stressed cattle is not only beneficial for decreasing their overall well-being, but also an aid for reducing heat load, maintaining DMI and productivity.

Based on the daily average CCI and predicted DWI, water consumption increased by 3.26 L for every 1 CCI unit (Table 5.5). Previous research has reported a range of 0.22 to 1.90 L increase in DWI for 1 °C increase in ambient air temperature (Arias and Mader, 2011; Hicks et al., 1988; Sexson et al., 2012). As previously stated, heat stressed cattle are consuming additional water to aid in heat evaporation through sweat and respiration. In addition to providing additional water, additional waterer space is also required. The NASEM (2016) and Mader and Davis (2004) report that the linear space at the water trough for feedlot cattle should be increased by 5 cm/head during times of extreme heat conditions. The implementaiton of additional heat stress mitigation techniques may also impact DWI of heat stress cattle. Additional research is needed to determine the impact shade and sprinkling have on RuTemp and DWI during heat or cold stress conditions.

IMPLICATIONS

The use of continuous RuTemp monitoring has proven effective in predicted DWI intake of feedlot steers. The use of RuTemp boluses would be beneficial for identification of illness, heat stress, or digestive issues prior to physical symptoms being present. Understanding the impact the CCI has on DWI, DMI and overall animal wellbeing is beneficial to implement management techniques. Use of the equation can be beneficial for continuous monitoring of water intake and can be used to predict water intakes based on the previous days' intakes. Additionally, equations can be developed to predict IDE throughout the d for continuous health monitoring. Providing an adequate amount of clean, fresh water to cattle can aid in heat dissipation through evaporative cooling, increased DMI, and overall well-being.

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Table 5.1: Environmental conditions for Stillwater Oklahoma

	Month			
Item	May	June	July	August
Ambient Temperature, °C	21.10	25.56	26.39	26.45
Rain Fall, cm	5.53	4.88	5.84	2.72
Humidity, %	74.19	67.49	67.19	70.23
Radiation, w/m^2	208.80	307.00	266.37	256.93
Wind Speed, m/hr	3.55	3.38	2.80	2.50
CCI[1]				
Average	20.47	26.85	28.28	28.95
Maximum	26.14	35.29	33.96	33.70

Environmental conditions obtained from the Oklahoma Mesonet for May to August 2013.

[1]Comprehensive climate index were adapted from Mader et al. (2010).

Table 5.2: Daily water intake prediction equation from rumen temperature[1] and environmental variables[2]

Variable	Estimate	P-value	R^2
Equation 1			
Intercept	-49.42	0.001	0.35
DMI[2], kg	1.35	0.001	
WaTemp[3], C	1.61	0.001	
Rain fall, mm	-0.89	0.08	
Solar radiation	0.13	0.002	
Relative humidity	-0.01	0.81	
Air Temperature, C	1.46	0.001	
Wind speed, mph	-1.72	0.001	
Total deviation[4]	0.23	0.001	
Equation 2			
Intercept	-56.04	0.001	0.35
WaTemp, C	1.41	0.001	
DMI, kg	1.60	0.001	
Average CCI[5]	0.76	0.001	
Maximum CCI[6]	0.50	0.001	
Total deviation	0.23	0.001	
	Predicted[8]	Actual[9]	
Water intake[7], L	51.74	51.56	

Rumen temperatures were recorded in 3 minutes intervals for 54 steers housed in the Insentec Monitoring System (Markenesse, Netherlands). The system is programmed for quantification of individual feed and water intakes for individual steers.
[1]Daily average environmental factors were collected for Stillwater, Oklahoma from the Oklahoma Mesonet, Mesonet.org.
[2]Feed intakes summed daily by the Insentec system.
[3]Water temperatures were recorded in 5 minute intervals for individual pens and averaged by d.
[4]Difference between hourly maximum rumen temperature and real time rumen temperatures. If the difference is >1.50% of real-time rumen temperatures, the drop was identified as an individual drinking event. Drinking events and deviations were summed daily.
[5]Daily average comprehensive climate index equations adapted from Mader et al. (2010) and recorded by the Oklahoma Mesonet.
[6]Daily maximum comprehensive climate index recorded by the Oklahoma Mesonet.
[7]Average daily water intake.
[8]Intakes were predicted by using equation 2 for steers that were housed within the Insentec System (Markenesse, Netherlands).
[9]Average daily water intakes for steers housed in Insentec Monitoring system.

Table 5.3: Comparison of daily water intake (DWI) prediction equations

Item		Equations			
		InSt[3]	Rumen Predicted[4]	Hicks et al.[5]	Arias and Mader[6]
Experiment 1					
Steers[1], n	54				
Average DWI, L		51.67	51.52	41.17	36.86
Average DMI, kg	10.80				
Experiment 2					
Steers[2], n	72				
Average DWI, L		.	45.44	39.67	31.41
Average DMI, kg	10.22				

[1]Steers housed in Insentec Monitoring System (InSt; Markenesse, Netherlands) in Stillwater Oklahoma. System is programmed for quantification of individual feed and water intakes.
[2]Steers housed in open-air, soil surface, feedlot pens in Stillwater Oklahoma. Daily water intakes are unknown.
[3]Daily summed intakes for individual steers.
[4]DWI = -56.04 + 1.41(water temperature, °C) + 1.60 (DMI, kg) + 0.76 (average CCI) + 0.50 (maximum CCI) + 0.23 (total deviation). CCI = comprehensive climate index (Mader et al., 2010) collected by the Oklahoma Mesonet (Mesonet.org). Total deviation = difference between hourly maximum rumen temperature and real-time rumen temperatures. If the differences was > 1.50% of real-time temperature, the drop was identified as an individual drinking event. Temperature deviation were summed daily.
[5]DWI = -6.07 + 0.71 (max temperature, °C) + 2.43 (DMI, kg) – 3.87 (precipitation, cm) – 4.43 (dietary salt, %). Dietary salt was 0.038% (Maxwell et al., 2015).
[6]DWI = 5.92 + 1.0 (DMI, kg) + 0.04 (solar radiation, w/m^2) + 0.45 (minimum temperature, °C). Environment variables for Stillwater Oklahoma for May to September 2013 were obtained from the Oklahoma Mesonet (Mesonet.org).

Table 5.4: Effects of comprehensive climate index stress threshold on predicted daily water intake (DWI) and dry matter intake (DMI)

Item	Stress Threshold[1]				SEM	*P* value
	No Stress	Mild	Moderate	Severe		
Predicted DWI, L[2]	36.35[d]	49.79[c]	53.14[b]	57.57[a]	1.265	<0.001
DMI, kg	10.35[a]	10.22[b]	10.17[b]	10.05[c]	0.16	0.02
DWI, L/DMI, kg	3.59[d]	4.59[c]	5.14[b]	5.73[a]	0.128	0.01
DMI, kg/DWI, L	0.30[c]	0.22[b]	0.20[a]	0.18[a]	0.006	0.01

[a-d] Means with unique superscripts within row differ when $P < 0.05$.

[1] Comprehensive climate index stress thresholds obtained from Mader et al. (2010); < 25 – no stress; 26 to 30 - mild stress; 31 to 35 – moderate; 36 to 40 – severe. Environmental conditions were recorded in 5 minute intervals for Stillwater Oklahoma by the Oklahoma Mesonet (Mesonet.org)

[2] Predicted DWI was calculated using the following equation: DWI = -56.04 + 1.41 (water temperature) + 1.60 (DMI) + 0.76 (average CCI) + 0.50 (maximum CCI) + 0.23 (total deviation). Total deviation is the difference between hourly maximum rumen temperature and real time rumen temperatures. If the difference is >1.50% of real-time rumen temperatures, the drop was identified as an individual drinking event. Drinking events and deviations were summed daily.

Table 5.5: Ratio[1] of predicted daily water intake (DWI)[2] to comprehensive climate index (CCI)[3]

Item	Ratio
DWI, L : CCI	3.26
CCI : DWI, L	0.32

[1]Average predicted DWI was regressed with average daily CCI and the equation of the line was used to calculated ratio.
[2]Predicted DWI was calculated using the following equation: DWI = -56.04 + 1.41 (water temperature) + 1.60 (DMI) + 0.76 (average CCI) + 0.50 (maximum CCI) + 0.23 (total deviation). Total deviation is the difference between hourly maximum rumen temperature and real time rumen temperatures. If the difference is >1.50% of real-time rumen temperatures, the drop was identified as an individual drinking event. Drinking events and deviations were summed daily.
[1] Comprehensive climate index obtained from Mader et al. (2010); < 25 – no stress; 26 to 30 - mild stress; 31 to 35 – moderate; 36 to 40 – severe. Environmental conditions were recorded in 5 minute intervals for Stillwater Oklahoma by the Oklahoma Mesonet (Mesonet.org)

Figure 5.1: Relationship between total deviation (a) [2]; water temperature (b) [3], average CCI (c) [4], maximum CCI (d) and DMI (e).

[1]DWI was calculated using the following the equation: DWI (L) = -56.04 + 1.41(water temperature) + 1.598(DMI) + 0.76(CCI) + 0.500(CCI_{max}) + 0.23(total deviation) [2]Difference between hourly maximum rumen temperature and real time rumen temperatures. If the difference is >1.50% of real-time rumen temperatures, the drop was identified as an individual drinking event. Drinking events and deviations were summed daily for total deviation. [3]Water temperature were recorded for individual pens in 5 min intervals and averaged by pen and d. [4]Comprehensive climate index was recorded from the Oklahoma Mesonet (Mesonet.org) in 5 min intervals and averaged by d. [5]DMI recorded for individual steers through the Insentec Monitoring system.

Figure 5.2: Relationship between predicted daily water intake (DWI)[1] and total deviation (a)[2], water temperature (b)[3], and average CCI (c)[4].

[1]DWI was calculated using the following the equation: DWI (L) = -56.04 + 1.41(water temperature) + 1.598(DMI) + 0.76(CCI) + 0.500(CCI_{max}) + 0.23(total deviation) [2]Difference between hourly maximum rumen temperature and real time rumen temperatures. If the difference is >1.50% of real-time rumen temperatures, the drop was identified as an individual drinking event. Drinking events and deviations were summed daily for total deviation. [3]Water temperature were recorded for individual pens in 5 min intervals and averaged by pen and d. [4]Comprehensive climate index was recorded from the Oklahoma Mesonet (Mesonet.org) in 5 min intervals and averaged by d.

Figure 4.1a

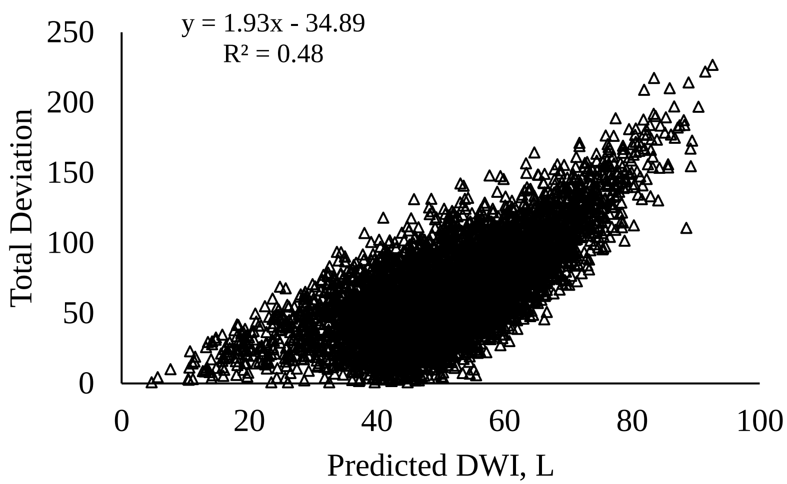


Figure 4.1b

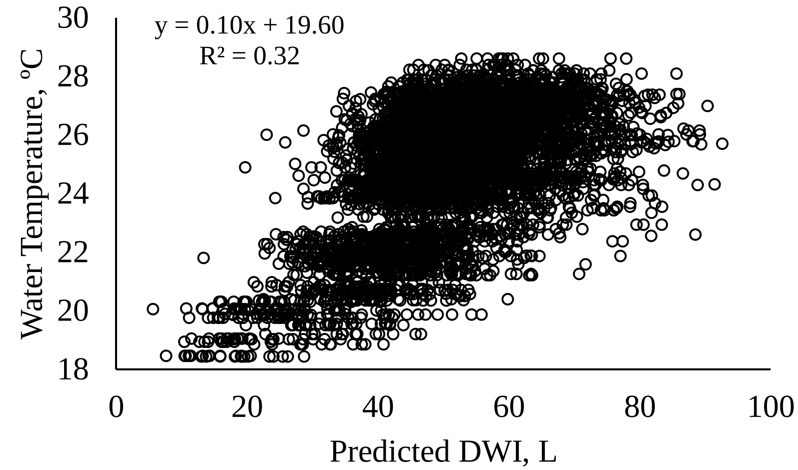


Figure 4.1c

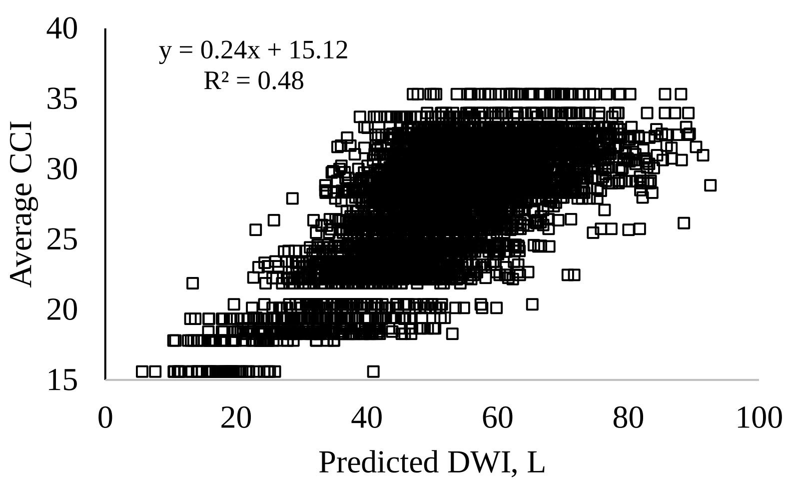
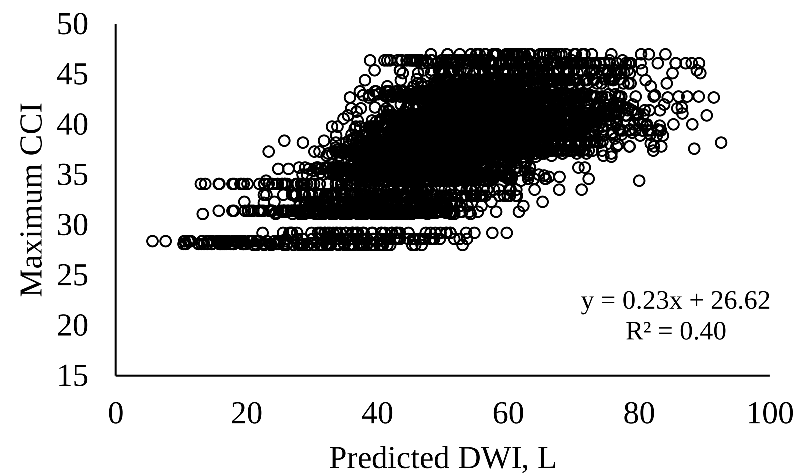


Figure 4.1d



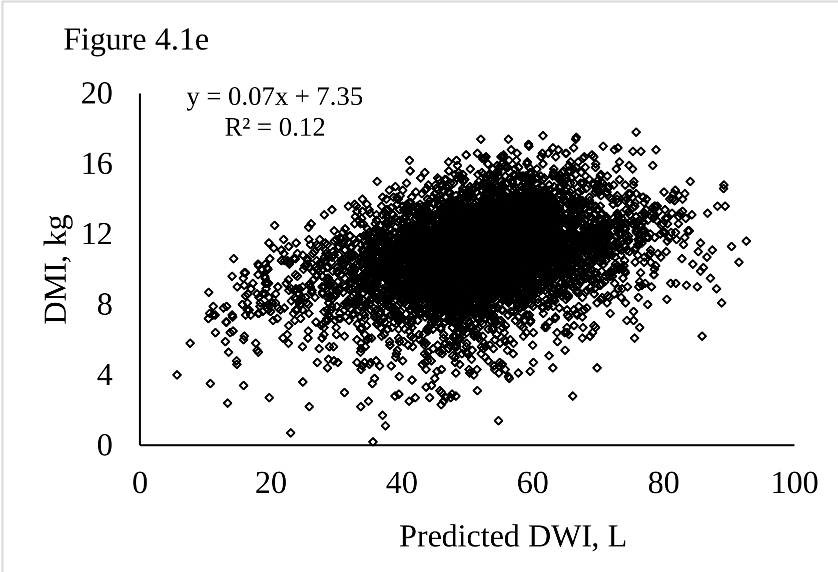


Figure 4.1e
y = 0.07x + 7.35
R² = 0.12
DMI, kg
Predicted DWI, L
0
4
8
12
16
20
0
20
40
60
80
100

Figure 4.2a

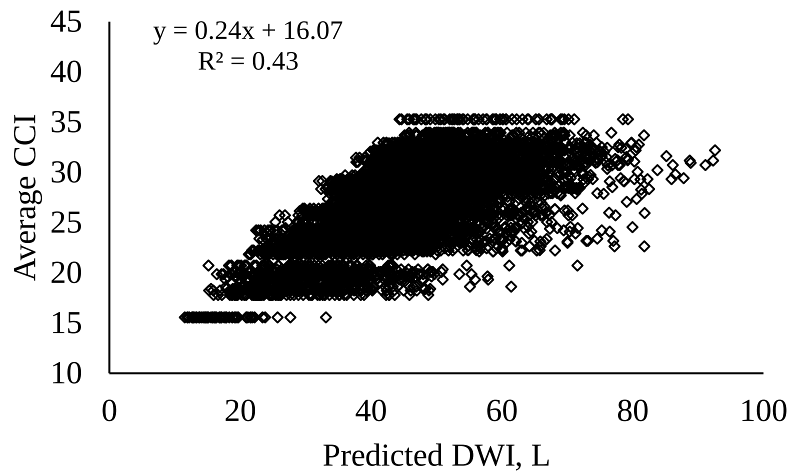
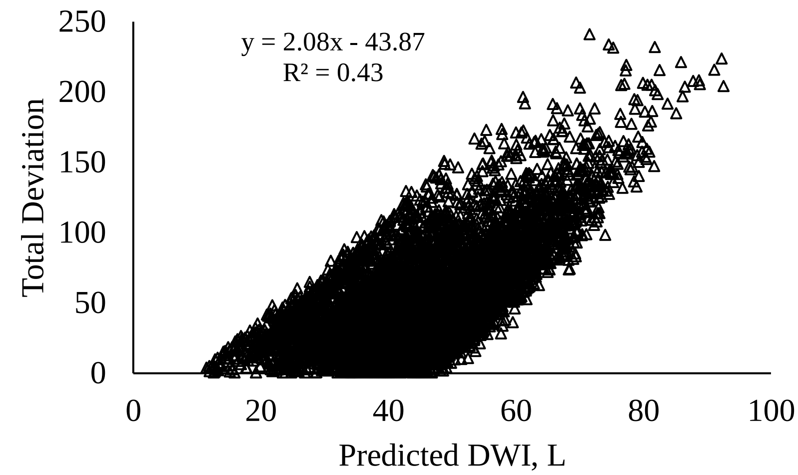


Figure 4.2b



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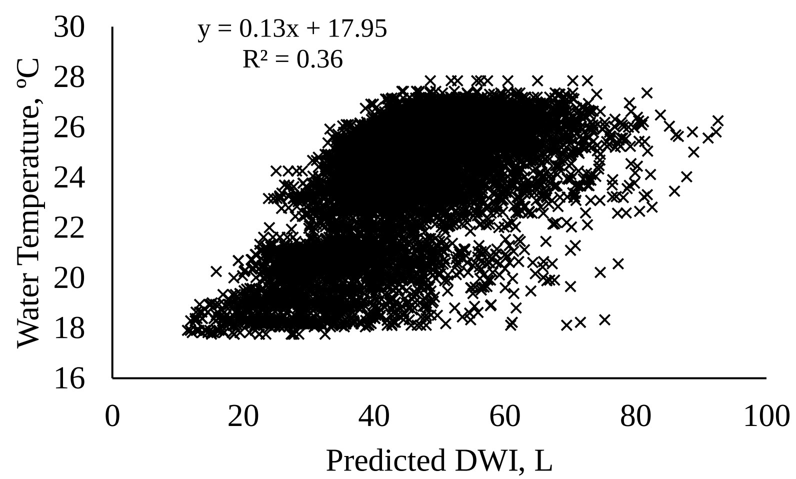

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